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गुरुकुल कांगड़ी विश्वविद्यालय, हरिद्वार
पुस्तकालय

विषय संख्या R 505
पुस्तक संख्या L84E V. 1-X
आगत पंजिका संख्या (Index)

पुस्तक पर किसी प्रकार का निशान लगाना वर्जित है । कृपया १५ दिन से अधिक समय तक पुस्तक अपने पास न रखें । ~~63115~~

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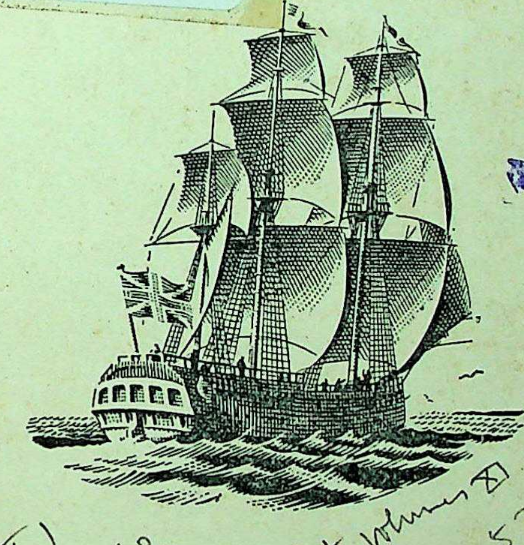

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गुरुकुल पुस्तकालय कांगड़ी

Made and printed in Great Britain at THE KYNOCH PRESS, *Witton, Birmingham, 6, for the publishers,*
IMPERIAL CHEMICAL INDUSTRIES LIMITED, *London, S.W.1*

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04 ESSAYS

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ENDEAVOUR

A quarterly review designed to record the
progress of the sciences in the service
of mankind

VOLUME X January 1951 NUMBER 37

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A Memorial to Ernest Rutherford

The achievement of Ernest Rutherford has the monumental simplicity that is characteristic of supreme greatness. To develop the current ideas of one's time, to extend gradually, by informed conjecture and patient endeavour, the boundaries of knowledge, is a service which properly suffices to bring fame and honours to men of science. Rutherford's exploit was of a different kind. He discovered in the exiguous space occupied by the atom a new world, a world of striking complexity which was revealed by marvellously planned and daringly executed exploration, a world which hosts of men of genius are now occupied in investigating. From the time, now nearly fifty years ago, when he first, with Soddy, put forward, and soon convincingly established, the hypothesis that atoms were disintegrating, with the liberation of energy stored somewhere in their recesses, to the day when he saw achieved, as the result of his constant and unswerving prosecution of one directed endeavour, the artificial transmutation of atoms and the subjugation of the nucleus, he was occupied in demolishing accepted ideas and creating a new and unified body of knowledge of supreme significance. He, at the end of his life, might well have said what Horace wrote proudly on the completion of the third book of the Odes: '*Exegi monumentum aere perennius*.' Horace did not contemplate enduring beyond the time when vestal virgins carried out their offices in the Capitol at Rome: Rutherford's name will certainly live as long as our present civilization, and may outlast it.

If, then, an appeal is today sent out by the Royal Society for funds to support a memorial to this great man, it is rather with the desire to pay a pious tribute to his memory than to perpetuate a name so secured and buttressed by his own acts, rather to promote designs which Rutherford would have approved than to approve Rutherford. Rutherford, it is true, was a man whose being was dominated by one great design, that of revealing secrets of atomic structure and atomic change: he possessed to an abnormal degree that power of concentration which Newton expressed in the words 'I keep the subject constantly before me, and wait till the first dawnings open little by little into the full and clear light.' But Rutherford was a much more normal man than Newton, possessed as he was by broad human interests and animated by a kindly heart that rejoiced in contact, and even in amiable dispute, with his fellow men. He was, from his first professorship, the ideal head of a laboratory: he loved to have round him a band of eager young—and not so young—men, to whom he could impart his latest thoughts and projects and communicate his enthusiasm. He would not have been happy, as were Cavendish and, in more recent times, Rayleigh, in solitary research: contact with research students stimulated him just as he stimulated them. Another of his human interests was a deep affection for New Zealand, his homeland, and for the Commonwealth in general. His native town was Nelson, and when he was raised to the peerage he took as his title Baron Rutherford of Nelson. His first professorship was at Montreal, where he passed some of his happiest and most productive years, and while Canada owes to Rutherford a debt which has always been generously acknowledged, Rutherford was always eager to admit that he owed much to Canada. Australia and South Africa also knew his genial influence and won his affection. Young men at work and the countries of the British Commonwealth were, then, dear to Rutherford's heart and an essential part of his life. Such considerations were, no doubt, dominant when the nature of the proposed Rutherford Memorial was deliberated by the Royal Society committee dealing with the matter. Appropriately enough, the chairman of this committee when the appeal went out was Australian-born Professor Oliphant: on his recent departure for his native land he has been succeeded by Sir Henry Tizard, who was an intimate friend of Rutherford and is, like Ulysses, a much experienced man.

The proposal set out in the appeal is that the memorial shall take two main forms, the first being Rutherford Scholarships for post-graduate students within the British Commonwealth, and the second a Rutherford Memorial Lecture, to be delivered at intervals by some leading man of science at selected university centres in the British Commonwealth overseas. Rutherford himself first came to England to work in the inspiring atmosphere of J. J. Thomson's laboratory as the result of the award of an 1851 Exhibition Science Scholarship, and there is no doubt that he would have warmly welcomed any plan, like the present, which will enable young men of proved ability to study here or in some other part of the Commonwealth

—for the proposal envisages that, within the Commonwealth, the holder of a Rutherford Scholarship may work anywhere except at the place of his graduation. Again, the Rutherford Memorial Lecture will enable a leader of science to see, in pleasant circumstances, the work proceeding in some distant university, as Rutherford loved to do, and to encourage young men, who have known him by name only, by his presence and interest. It is difficult to think of any way in which the fellowship of science within the Commonwealth could be more effectively stimulated. A subsidiary proposal is that Rutherford's correspondence, in copy if necessary, shall be collected under the direction of some skilled hand, and, presumably, kept in some centre where it will be readily available to serious students. The desirability of this requires no comment. In the printed appeal nothing is said of a further proposal to arrange for a collected edition, in worthy form, of Rutherford's papers and addresses, but it is believed that this, too, is to be put in hand. Possibly it is considered that the sale of copies will ultimately pay the expenses of publication, but funds will be required in the first instance. Everything that Rutherford wrote is stimulating, and it is to be anticipated that even those familiar with his work will find in such a collected edition, when it appears, many inspiring things that are at present hidden in publications a little apart from the standard periodicals.

It will be admitted on all hands that the proposed memorial scheme has been wisely planned and is deserving of the strongest support from all who have the interests of science and the Commonwealth at heart. The only suggestion that seems appropriate is that a slight extension may be desirable which will, in some manner, include in the scheme admirers of Rutherford outside the Commonwealth. He had many warm friends in the United States. As a young man of thirty he attended a meeting of the American Physical Society, and he wrote 'The meeting was held in Columbia University, where I gave two papers which were pretty well received, as I am the only worker in the field of excited radioactivity in the English-speaking world,' and from that time onward his relations with America were of the warmest. Boltwood was one of his closest friends, and, when the Rutherford correspondence is collected, will be among the most prominent names, but there were many others. 'The English-speaking world,' he wrote: could not the scheme be made to contemplate some occasional gesture to show that he was almost as much at home in the States as in Canada? It is certain that many friends there will respond generously to the appeal: it would be pleasant to think that from time to time a Rutherford Memorial Lecturer, visiting Canada, perhaps, will cross the border in an official capacity, since he is sure to cross it in any case.

'Nothing was so refreshing or so inspiring,' wrote Geiger of an incident that occurred when he was at Manchester, 'as to spend an hour in this way, alone with Rutherford.' The great man has gone and no one will ever again have this felicity. The present memorial scheme has, however, the great merit that it goes as far as seems possible to perpetuate Rutherford's personality, to make his memory a living thing. A statue, a great hall, soon lose their compelling significance: of the thousands who enter the Albert Hall, how many are brought to remember the good Prince Consort? But the young man who receives a scholarship in Rutherford's name is bound to think of how the great man himself was started on his career by such a scholarship: the Memorial Lecturers will certainly be men familiar with Rutherford's work and, in all probability, will be actually engaged in developing some consequence of it. The correspondence, mostly so informal, so headlong, will be almost a living voice. We warmly commend to all our readers the memorial scheme so opportunely brought forward and so wisely planned by the Royal Society.

Pollen analysis (Palynology)

H. GODWIN

Although the Quaternary is the most recent of all geological ages, its dating presents problems which are only just beginning to be overcome. The analysis of pollen residues recovered from peat deposits and the beds of former lakes has, however, proved exceptionally helpful as a means of dating deposits, and has provided astonishingly complete information about the great climatic changes which have occurred in Europe since the last glacial age. This method of dating can be co-ordinated satisfactorily with other methods.

Pollen analysis in its modern form owes its origin to the Swedish geologist Lennart von Post, who established the analysis of quantitative changes in fossil tree-pollen as a method of attack upon the complex problems of Quaternary history. In essence, the method was one of micro-palaeontology or, perhaps better, of palaeo-ecology; it certainly had essentially geological applications, and it is in this sense that pollen analysis continues chiefly to be used and to be understood. The standard of microscopic investigation was progressively raised, particularly at the onset by Wodehouse in America. The study of pollen morphology for its own sake was developed by various workers, chief among whom is now G. Erdtman, whose institute in Stockholm has an unrivalled type-collection of pollen from various parts of the world. He has applied the results of comparative pollen morphology with much success to problems of the relationship between the families and genera of flowering plants. A useful, if restricted, field of research has been in the pollen content of honey, both recent and prehistoric, and a far wider field has been opened through research upon the allergic diseases (hay fever, etc.) associated with airborne pollen and spores. For some years, active work of this kind has been in progress in the United States upon the seasonal liberation, spread, and deposition of the pollen types most generally associated with hay fever, and in Britain valuable pioneer work has been done by Hyde and Williams from their research centre in South Wales. Pollen identifications have also been employed in research upon the biology of pollination and upon the structure and movement of glaciers. To cover all these various forms of pollen and spore investigation, Hyde has proposed the useful term palynology.

PRINCIPLES

An essential part of the reproduction of the higher plants through seeds is the prior formation and liberation of the pollen grains, and their transfer from the stamens to the receptive stigmas. The vast array of flower forms and pollination mechanisms has evolved, in response to evolutionary pressure, to perfect this transfer. The spores of mosses, ferns, and gymnosperms are dispersed by the wind, and a considerable proportion of flowering plants, like their evolutionary predecessors, still have wind-carried pollen (microspores), although insect pollination now prevails among them.

Vast numbers of pollen grains are set free into the air during flowering, even by entomophilous plants, and the small size of the liberated grains makes them fall so slowly that they can be carried long distances by air currents and reach great altitudes in the atmosphere. Only a minute proportion reaches stigmas where it can germinate successfully. The vast majority of the pollen grains gradually sink and come to rest on lakes, snowfields, oceans, and land.

Most of them are destroyed, but in some situations, especially those where oxygen is deficient, they may be embedded and preserved. This is especially so in the anaerobic muds at the bottom of lakes, and in growing peat deposits. As such deposits accumulate they bury the showers of pollen falling into them, so building millimetre by millimetre a consecutive record of the plant life of the period of formation of the deposit. The significance of pollen analysis rests upon the legibility, permanence, and informativeness of this record. The pollen grains exhibit a striking range of characters by which identification is possible, sometimes of species, very often of genera or families. There is a wide range of size and of shape; of number, shape, and disposition of germ pores or other openings in the wall; of wall structure and thickness; and of a surface morphology often involving elaborate and intricate sculptures and networks.

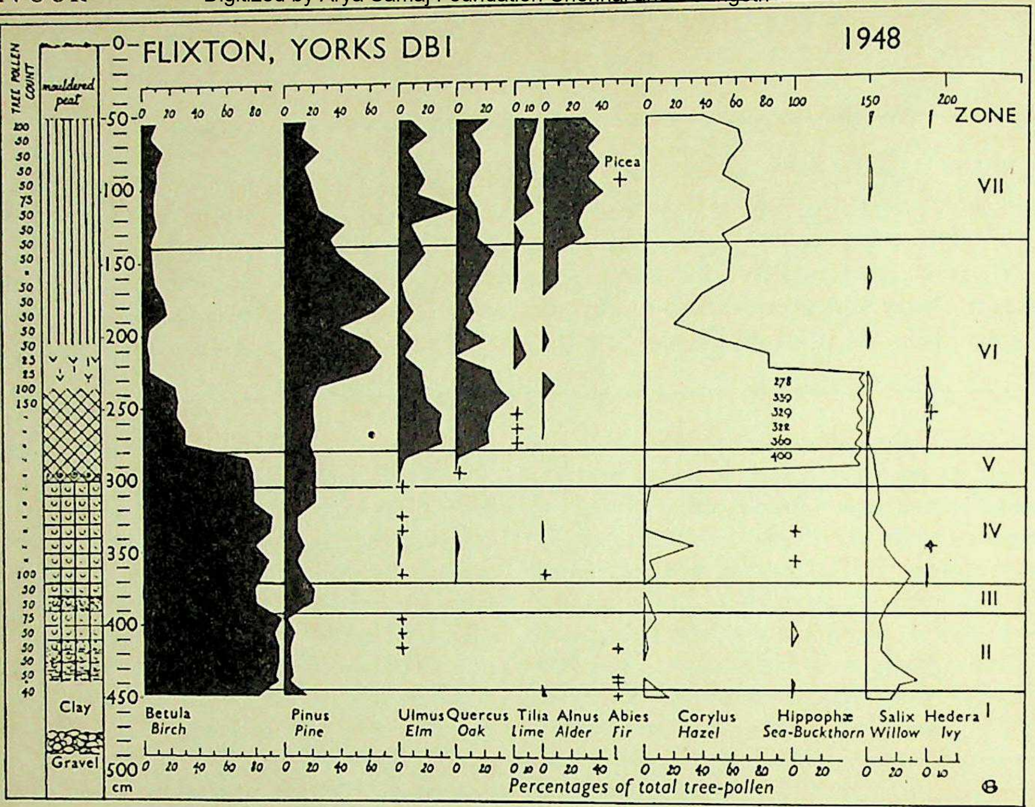


FIGURE 1 – *Pollen diagram, Flixton, Yorkshire (tree-pollen).*

The inner wall of the pollen grain is not long preserved, but the outer wall (retaining all the characters mentioned above and of quite different origin and constitution) is extremely resistant, in suitable materials remaining apparently unaltered for thousands and indeed millions of years. By simple mechanical and chemical treatments the grains may be isolated from the matrix which preserved them, and can be concentrated, mounted, and examined microscopically.

The value of the pollen identifications thus made rests not only upon the demonstration that particular species or genera have been present in the locality but even more upon the wider picture they present of the vegetational cover of a whole district or region. Since the dominant species of the great natural forest communities of western Europe are for the most part wind-pollinated trees, as are also the grasses and sedges which dominate other extensive communities, the pollen rain fully represents all of them, and it will be seen that the successive layers of a lake or peat bog can therefore picture the changing vegetational cover over long periods of time. The history of such major communities is of interest in many ways. They were, of course, the habitat, and the controlling environment, for populations of other plants and of animals, so that the history of the European fauna and flora is scarcely to be understood without knowledge of them. Equally they were the home and background of races of prehistoric human beings, whose livelihood and culture depended upon the natural environment.

Most important of all, the presence and extent of these communities were determined by prevalent climatic conditions, so that the study of past climates is implicit in the study of these past types of vegetation. It can hardly be supposed that any cause other than climatic can have been responsible for the broad sequence of change shown in the great number of pollen diagrams worked out for western Europe and North America.

A typical diagram is that shown in figure 1, which gives the results of analysing the muds from the floor of the ancient Lake Pickering which formerly existed between the Yorkshire Moors and the Wolds (England). The samples were taken by a special drill or sampler at intervals of 5 or 10 cm. For each sample the proportions of the various tree genera present are expressed (for lack of an absolute standard) as a percentage of the total tree pollen. If we consider the broad results it will be apparent that the lake deposits reflect profound vegetational changes, from a long initial period of dominance of birch pollen, through a stage of elm, oak, and hazel (the latter in great abundance), a phase of increased importance of pine, and then, with the oak and elm joined by the lime and alder, a period in which the deciduous mixed-oak-forest trees clearly outweighed birch and pine. We may assume that the pollen represents in a rough manner the proportions of the trees from which it came, and it is apparent that this sequence of samples does in fact record the vegetational response to climatic amelioration since the last Ice Age. The time sequence of forest dominance here recorded repeats in some degree the present latitudinal sequences of forest belts governed by a similar climatic sequence. The most exigent of the tree genera, *Tilia* and *Alnus*, do not become abundant until the uppermost part of the diagram, which falls within the so-called post-glacial climatic optimum. The uppermost layers of the lake deposits have been lost by drainage and wastage, otherwise we could have seen in them the record also of climatic regression towards the cooler conditions of today; these are exhibited in the diagram from Somerset, England (figure 2).

Interesting as this single diagram is, its value is multiplied very greatly when it is compared with other diagrams compiled from suitable deposits throughout Britain or throughout western Europe. Such diagrams are found to correspond with one another to a truly extraordinary degree, and it has proved practicable to recognize over wide areas equivalent zones of vegetational development. Those for the Flixton diagram are the zones used for the British Isles; they bear a close relationship to the zoning of the nearby continent. The various regions of western Europe naturally do not show an identical history of forest evolution, but they have parallel and equivalent histories, just as today they have different natural vegetation types.

Even if we could not recognize the origin of a single fossil pollen grain, but had to refer to them by letters or by numbers, a scientific tool of great value would be in our hands, for the ubiquity of these micro-fossils, and the regularity of the changes in their frequency, clearly provide us with a time-scale against which we can record all the events of the periods covered by the deposition of pollen-bearing sediments. Knowing the identity of so many grains gives us the added power of recognizing vegetational and climatic changes.

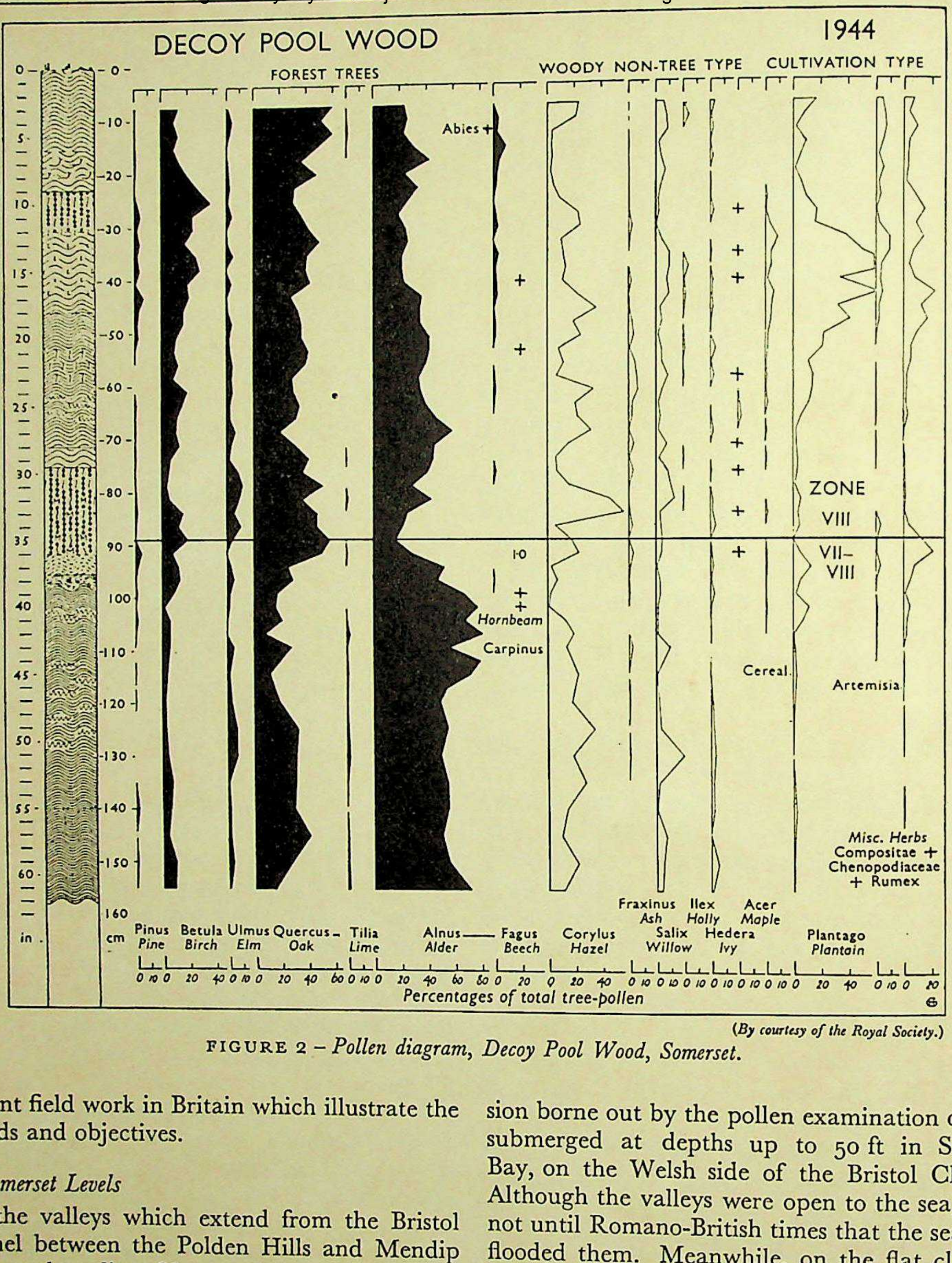
It further happens that the periods to which pollen analysis can most easily be applied, the post-glacial and the interglacial periods, are precisely those where chronological scales have hitherto been lacking. The time involved in them has been too short for the evolution and dispersal of organisms capable of serving as geological zone-fossils in the ordinary sense, and alternative indices, such as the artifacts of human cultures, occur far too locally and too sparsely. Nevertheless, geological changes have by no means ceased during this time. There have been the great and repeated climatic shifts from glacial to interglacial climates; the corresponding cycles of weathering, erosion, transport, and deposition; the alteration of ocean level by locking and unlocking of water in the world's ice-sheets; the differential bending of the earth's crust by the ice load upon it; the formation and filling of lakes; the growth of peat bogs; the modifications of rivers and coastlines; and so forth. Always associated with these have been the dependent migrations and evolution of the fauna and flora, and of man himself. It is indeed evident that, for the purpose of understanding present biological life on the earth, we must give the closest attention to all evidence of what happened in these periods.

APPLICATION TO QUATERNARY HISTORY

In making use of pollen analysis as a tool in Quaternary research, we seek to bring the conclusions which it yields about vegetational history into conformity with those derived independently from the study of archaeology, climatology, and geology. The evidence from each field has its own especial value and weaknesses, and none takes priority over the others; in the end, however attained, the results from all must form a coherent scheme.

It therefore follows that stratigraphic conditions should be sought where pollen analysis can be related to phenomena of several fields of Quaternary interest. Similarly one must constantly undertake pollen analyses of well-characterized geological situations, and settlements showing standard archaeological cultures, so that the scheme of pollen zoning can be firmly linked to as many other time-sequences as possible. Only when this has been done can pollen analysis serve the more spectacular purpose of dating objects or events of otherwise unknown age.

It is not practicable in this short space to describe even in outline the great field of Quaternary research in relation to pollen analysis, and it must suffice to refer briefly to a very few instances



(*By courtesy of the Royal Society.*)

FIGURE 2 – *Pollen diagram, Decoy Pool Wood, Somerset.*

of recent field work in Britain which illustrate the methods and objectives.

The Somerset Levels

In the valleys which extend from the Bristol Channel between the Polden Hills and Mendip there are the relics of huge sphagnum bogs, now being actively cut for peat. In this intensive excavation much evidence of value for Quaternary history has come to light, and pollen analysis has been frequently made there. The bottoms of the valleys are filled with brackish-water clay to about present sea-level, and pollen analysis of the immediately overlying peat, and of intercalated seams, shows that the marine transgression had been completed by the end of zone VI, a conclusion borne out by the pollen examination of peats submerged at depths up to 50 ft in Swansea Bay, on the Welsh side of the Bristol Channel. Although the valleys were open to the sea, it was not until Romano-British times that the sea again flooded them. Meanwhile, on the flat clay surface, reed and sedge fen grew and then gave place to so-called ombrogenous raised-bog. Such bogs, built chiefly of sphagnum, depend upon direct rainfall for their water supply, and react quickly to climatic changes. Thus, in profiles now being exposed, horizontal banding of different peat types affords evidence of past climatic change. The most striking horizon of this kind reveals on investigation that the bogs, which had become dry and covered with ling (*Calluna*) and cotton-grass (*Eriophorum*), were suddenly covered with a deep growth of the great prickly sedge (*Cladium mariscus*) and associated fen species. This change can be interpreted only as due to flooding of the whole valley system by calcareous water from the limestone hills during a period of greatly increased wetness. The date of this event is established by two lines of evidence, pollen-analytical and archaeological. The pollen diagrams all indicate that at the horizon of this change the composition of the upland forests underwent severe changes. The lime tree greatly decreased, alder also diminished, there was a substantial increase in birch, and a smaller increase in pine, while from this time onwards beech pollen appeared in small but consistent amounts. These changes, which are used to define the boundary between pollen zones VII and VIII, were caused by a general climatic worsening found over the whole of western Europe, dated by archaeological finds to the transition from the Bronze Age to the Iron Age, and marked in innumerable peat bogs by 'recurrence surfaces' similar in character and significance to those in the Somerset bogs. The non-tree pollen confirms in detail the evidence of the gross peat analysis with regard to the plant communities growing directly on the bog throughout these changes.

As long as the climate and the bogs were dry, prehistoric man had little difficulty in crossing from ridge to ridge of solid ground, but as the swamping of the bog surfaces progressed he was forced to construct wooden trackways to maintain such routes. These could not be used for long; they were quickly engulfed in the growing morass of *Cladium*. Thus peat-diggers often encounter prehistoric trackways, and always find them at the level of the swamping surfaces. It is of great interest to discover that the timbers still carry the marks of the late Bronze Age axes by which they were cut, and that finds of middle Bronze Age spears come from only slightly lower in the bog stratigraphy. Confirmation of the age of the swamping surface comes from finds (also consistent with pollen analysis) of Neolithic pottery from substantially below, and of many Romano-British objects from substantially above, this level.

A further feature of interest is that the non-tree pollen discloses, by changes in the frequency of weed plants, the introduction, expansion, and contraction of agriculture in the region. It seems evident that cultivation occurred in the Bronze Age, suffered some setback from the climatic deterioration, and increased to much greater extent in late Iron Age and early and middle Romano-British times. The nature of the evidence for forest clearance is discussed later. The pollen curves of figure 2 show most of the major features to which we have referred.

Lake Pickering, Yorkshire

The retreat of the last ice sheet from east Yorkshire left a long, shallow lake ponded up at the seaward end. Through the waters of the lake morainic islands rose at intervals, and recent discoveries have shown that many of them were densely occupied by prehistoric hunters. Series of borings across the deepest parts of the lake show a stratigraphy typical of the late glacial period, and a long pollen series yields the diagram already described. Excavation on the flanks of one of the islands has shown that the prehistoric occupants built extensive platforms of birch branches beside the shore, in and upon which there is a great wealth of archaeological material: flint, antler, bone, wood, bark, and even amber, preserved by submergence in the rising water of the lake. It is evident from the artifacts that the site was occupied by Mesolithic people who had affinities on the one hand with the upper Palaeolithic cultures of Meiendorf in Holstein, and on the other with the Maglemose cultures of Denmark, the one late Glacial in date and the other Boreal, that is to say from the period of first expansion of the mixed-oak-forest.

At Flixton, the earliest of the Lake Pickering sites to be investigated (though not the most productive), it was possible to trace the débris of the occupation site laterally into the lake deposits, and so to bring it within a short vertical pollen series. This latter, fitted to the long lake-series, shows clearly that the occupation must be referred to the stage of closed forest immediately before the expansion of hazel and the mixed-oak-forest. It is thus earlier than any previously described Mesolithic culture in Britain. Nevertheless it seems apparent that, falling as it does near the close of zone IV or the opening of zone V, it relates to a period of closed forests, though these were birch and pine only.

This conclusion is confirmed by the identification of the abundant remains of forest animals. These include great quantities of the red deer (*Cervus elaphus*), some elk (*Alces alces*), roe deer (*Capreolus capreolus*), pig, a large species of *Bos*, and the fur-bearing fox, martin, badger, and beaver. There have been found various stages in the manufacture of barbed spears from the red-deer antlers; the abundance of these completed implements strongly characterizes the cultures, and it is interesting to note that in two previous instances of their discovery in Britain it has been possible to date them by pollen analysis. One of these was at the nearby cliff-site at Skipsea, where the implements were shown to have been at least as old as the Boreal period. The other was the recovery of such an implement from a lump of peat dredged from the floor of the North Sea in 19 fathoms of water by a trawler fishing on the Leman and Ower banks. Samples of peat attached to the mineral ground at this site were analysed, and were shown to have formed in the period just before and during the first expansion of the hazel and the mixed-oak-forests. It is therefore evident that at the time of this Mesolithic settlement in Yorkshire the North Sea basin was still dry, and that not only might the folk of the time have crossed directly between Britain and the continent of Europe, but that some of them did.

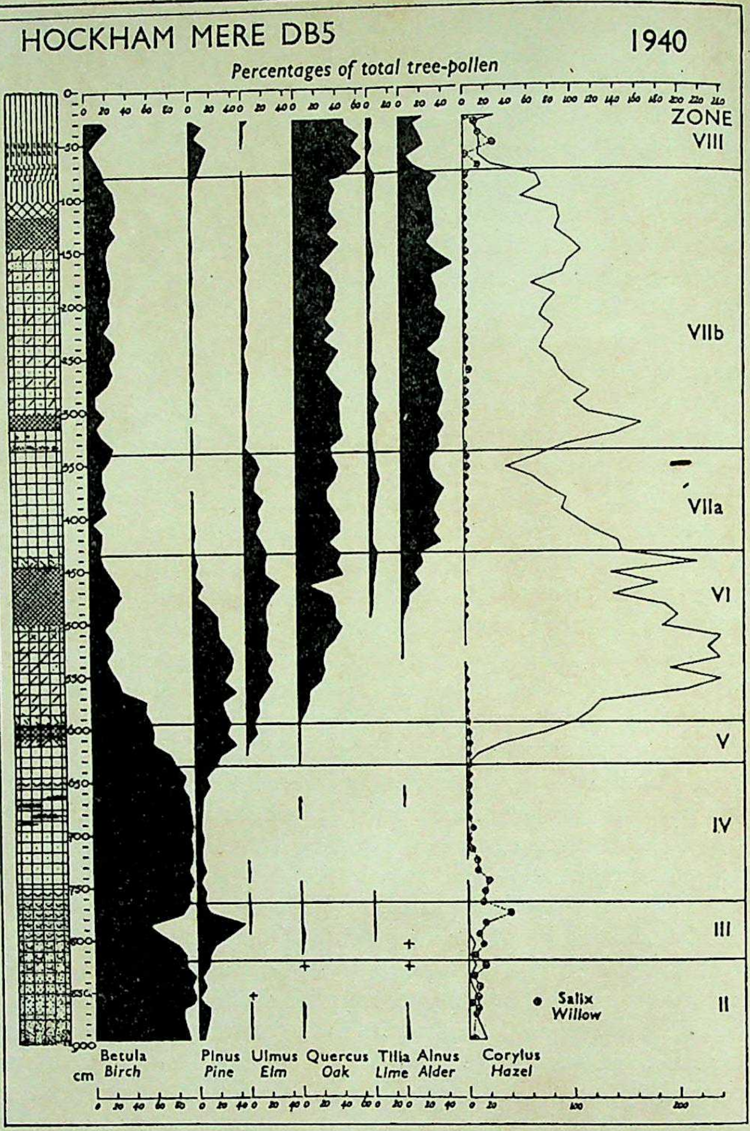


FIGURE 3 – *Pollen diagram, Hockham Mere (tree-pollen).*

DEFORESTATION AND HUMAN INFLUENCE

The technique of pollen analysis was based, as we have seen, very largely on the premise that the vegetational changes which it records are universally co-ordinated, since they have a common climatic cause. In the natural ecosystems of the remote past, man, hardly less than other animals, was subject to environmental control, and the hunter and fisher had an economy, tools, and customs immediately related to the forest or tundra in which he lived. Gradually this relation altered; the stone axe, fire, domesticated animals, metal tools, and tillage were agencies by which man began himself to exert influence upon his natural surroundings. At first puny, these efforts have gained the power and momentum which today call for the fullest efforts of conscious conservation policies if the very means of survival of humanity are not to be destroyed by them. The initiation and progress of this process are also, like the preceding 'natural' evolution, to be found recorded in the pollen diagrams of western Europe.

It has been known for some time that in a general way it is possible to distinguish the pollen of cultivated cereals from that of most wild grasses —a matter chiefly of size—and it has been shown that pollen of 'Cerealia' type was represented in some German diagrams by continuous curves from the Middle Ages onwards. Only within the last decade, however, has it been demonstrated that Neolithic forest clearance could be unmistakably recognized. Iversen, working in Denmark, was able to show that, at certain lake sites, ash from recognized Neolithic shore settlements was embedded in the lake muds at levels where the tree-pollen curves indicated sudden but orderly displacements. The curves showed, in fact, the local clearance by fire of the dominant oaks, the

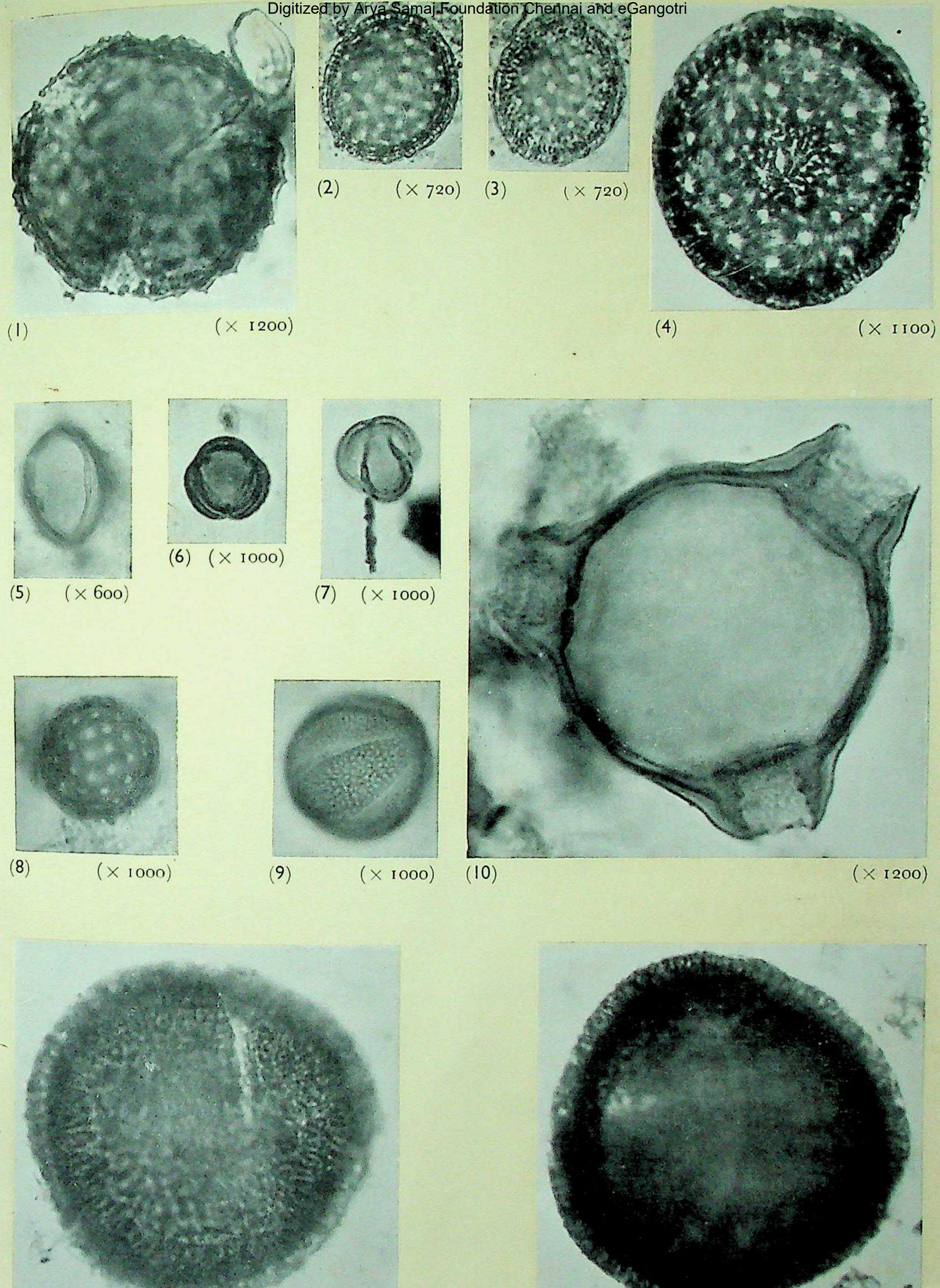
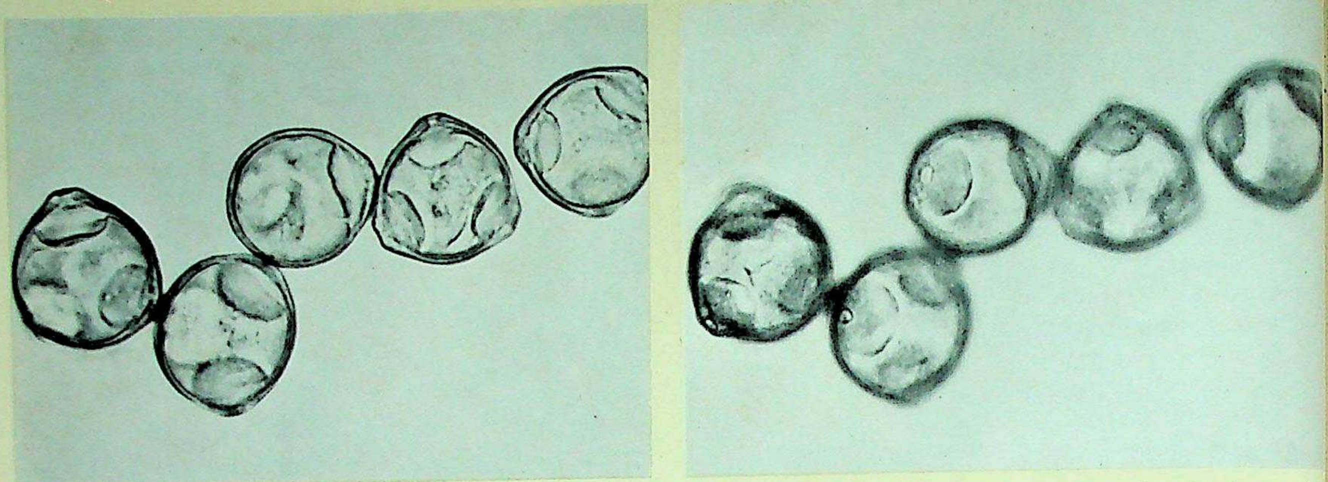
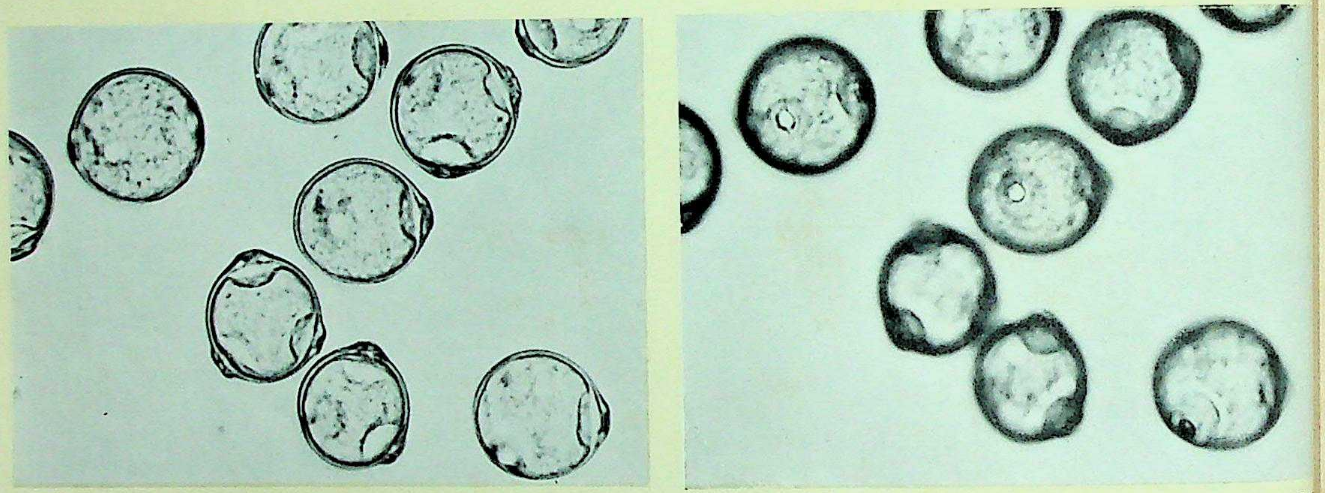

(1) (× 1200)
(2) (× 720)
(3) (× 720)
(4) (× 1100)
(5) (× 600)
(6) (× 1000)
(7) (× 1000)
(8) (× 1000)
(9) (× 1000)
(10) (× 1200)
(11) (× 1000)
(12) (× 1000)

FIGURE 4 – *Photographs of fossil pollen grains from late-glacial muds at Nazeing in the Lea Valley, north of London.* (1) Valeriana; (2) *and* (3) Polemonium caeruleum *in two planes of focus to show the characteristic pores and wall structure;* (4) *Recent pollen of the same species for comparison and at higher magnification;* (5) Helianthemum *cf.* chamaecistus; (6) Artemisia *sp.;* (7) Ulmaria; (8) Chenopodium *sp.;* (9) *six-furrowed grain of the* Labiatae; (10) Epilobium *sp.;* (11) *and* (12) Succisa pratensis, *the same grain at two depths of focus.*



FIGURES 5 *and* 6 – *Pollen grains of* Corylus avellana (*hazel*) *in optical section and in surface view, showing the characteristi pores.* (× 800)



FIGURES 7 *and* 8 – *Pollen grains of* Betula pendula (*birch*) *in optical section and in surface view. Note how the pores dif from those of* Corylus. (× 800)

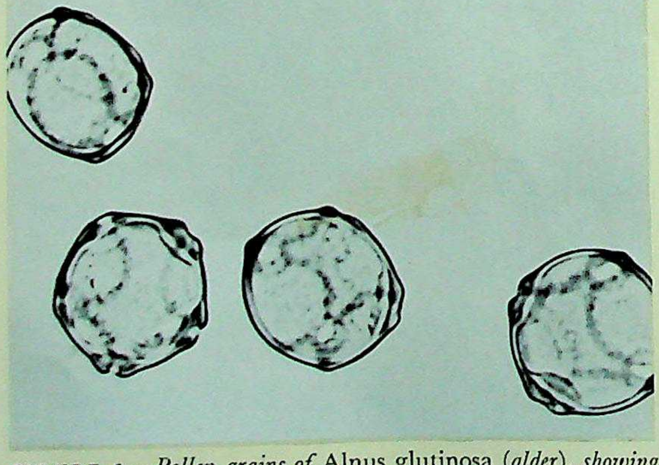


FIGURE 9 – *Pollen grains of* Alnus glutinosa (*alder*), *showing the curved bands running internally between the ringed pores.* (× 800)

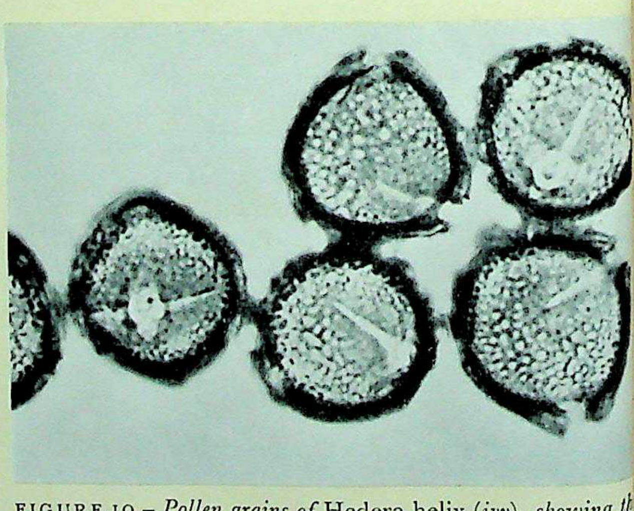


FIGURE 10 – *Pollen grains of* Hedera helix (*ivy*), *showing th furrows, each with a central circular pore, and a heavily sculptu surface.* (× 800)

(*Photographs 5–10 published by courtesy of Mr H. A. Hyde and of the Asthma and Allergy Research Unit, St David's Hospital, Car*

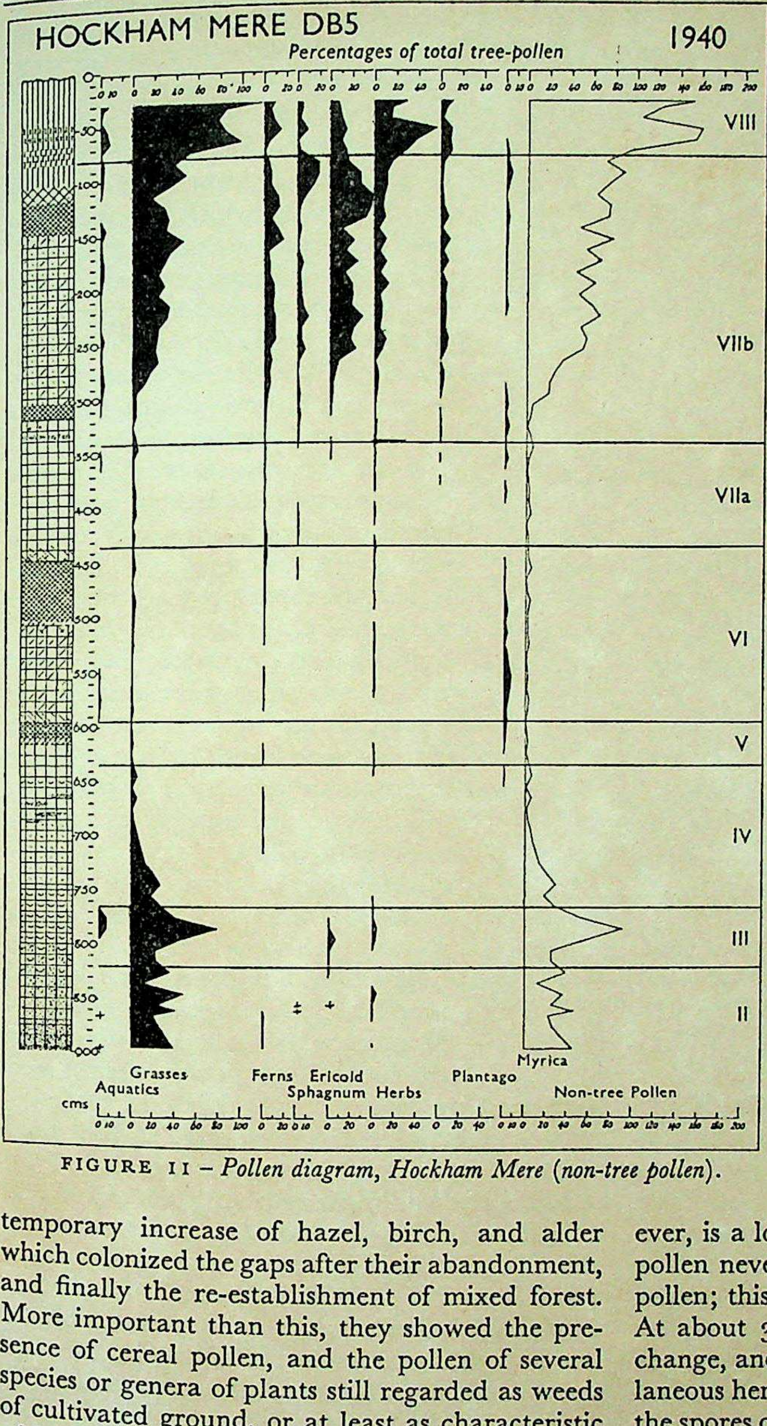


FIGURE 11 – *Pollen diagram, Hockham Mere (non-tree pollen).*

temporary increase of hazel, birch, and alder which colonized the gaps after their abandonment, and finally the re-establishment of mixed forest. More important than this, they showed the presence of cereal pollen, and the pollen of several species or genera of plants still regarded as weeds of cultivated ground, or at least as characteristic of broken or open sites. Prominent among them is the ribwort plantain (*Plantago lanceolata*), pollen of which can be distinguished from that of other plantains, and *Artemisia*, a genus of wind-pollinated *Compositae*. For the sandy heath country of Jutland, Iversen was able to confirm that the treeless heaths of the present day originated in prehistoric oak-birch forest; the easily recognizable pollen of the dominant heath shrubs (*Calluna* and other ericoid genera) extended back only to the Iron Age, before which the landscape was occupied by almost continuous forest.

These discoveries had their counterpart in Britain, where similar investigations had been made in the great heathland areas of East Anglia, the so-called Breckland. An ancient lake in the north of this region, Hockham Mere, partially drained in Tudor times, was shown still to contain 10 or 12 metres depth of organic lake mud, which when pollen-analysed revealed the history of the surrounding land right back to late glacial times. The tree-pollen diagram (figure 3) is remarkably uniform, and is clearly undisturbed by local influences such as complicate the diagrams of lake margins, wooded fens, and bogs. In it may be recognized all the leading features of the British pollen zonation. We may note that at about 330 cm falls the boundary between zones VII*a* and VII*b*, where the sharp decline in importance of the elm is a feature of all west European diagrams; this is known to correspond with the beginnings of Neolithic culture. To this diagram we add that for the non-tree pollen to which the same zones have been transferred. It will be observed that during the late glacial period (zones II and III) the openness of the birch woodland is demonstrated by the high values for non-tree pollen, chiefly grasses. Following this, however, is a long period in which the total non-tree pollen never amounts to 10 per cent. of the tree pollen; this must indicate closed forest conditions. At about 300 cm the diagram shows a startling change, and pollen of grasses, heather, and miscellaneous herbs increases remarkably, together with the spores of sphagnum and of ferns. They quickly equal 60 per cent. of the total tree pollen, and evidently indicate the conversion of much of the forest into open heaths. It will be observed that during this time there is established a continuous curve for that characteristic species, *Plantago lanceolata*.

Deforestation thus evidently became serious in Neolithic times, and it is significant that within 10 miles (16 km) of Hockham Mere is the great

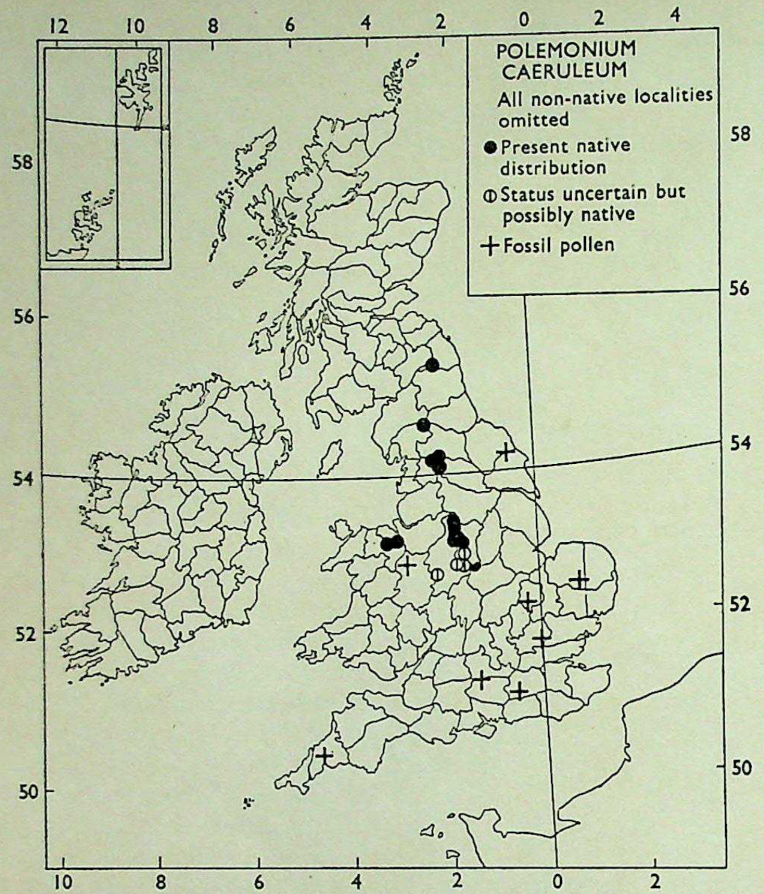

POLEMONIUM CAERULEUM
All non-native localities omitted
● Present native distribution
⊕ Status uncertain but possibly native
+ Fossil pollen
12
10
8
6
4
2
0
2
4
58
56
54
52
50

FIGURE 12 – *Present and former distribution of* Polemonium caeruleum *in the British Isles. The discoveries of pollen in late glacial deposits show how extensive has been the range of the plant, which has been found at points as widely separated as Cornwall and the Scottish border.*

Neolithic flint mine of Grimes' Graves, furnishing direct evidence of prehistoric occupation at this period. At a depth of 70–80 cm the non-tree pollen curves show substantial increases, and these may be dated by reference to the tree-pollen diagram, where a series of modifications indicates the transition from zone VII to zone VIII in response to the widespread climatic deterioration of that time. This falls at the transition from Bronze Age to Iron Age in Britain, and it seems evident that the clearances which began in Neolithic times were greatly extended in the Iron Age. The explanation of the Breckland heaths in terms of such anthropogenous origin represents a considerable step forward in understanding the ecology of this region.

THE LATE GLACIAL PERIOD

As the picture of the post-glacial forest history of western Europe began to take unmistakable shape, pollen analysts began to thrust back their inquiries into the preceding late glacial period. They examined the phenomena associated with the so-called Allerød oscillation, a temporary phase of warmth followed by returning cold, which occurred immediately before the general post-glacial climatic amelioration. This oscillation is represented by organic lake and basin deposits overlying glacial till (boulder clay) and covered by earth brought down into the basin by alternate freezing and thawing. The climatic improvement of the oscillation was indicated not merely by the fact that organic muds unmixed with mineral matter grew in the lakes, but by the relatively temperate flora of these organic muds, as indicated by fruits, seeds, leaves, etc., in contrast with the more northern flora of the mineral soils above and below, which gave to these layers the names of the lower and upper Dryas clays.

The application of pollen analysis to deposits of this period was much facilitated by improvements in experience and technique, which by then allowed pollen of many herbaceous genera to be recognized. In southern Scandinavia, where these investigations began, it was soon realized that the lower Dryas clays, the Allerød layer, and the upper Dryas clays had clear expression in the pollen diagrams, and they have been equated there and in Britain with pollen zones I, II, and III. The post-glacial period which begins with zone IV opens by a remarkable reduction in the ratio of non-tree pollen to tree pollen, a constant expression of the development of closed birch woods, and the exclusion of herbaceous vegetation. The late glacial non-tree pollen was overwhelmingly derived from grasses and sedges, the ericoid shrubs of modern Europe north of the forest line being unimportant. The frequency of pollen of birches, and local macroscopic fossils, show, however, that clumps of these trees occurred here and there, and the name park-tundra has been coined to express the general character of the vegetation. Certain species and genera have come to be recognized through their pollen as very highly characteristic of this late glacial vegetation. *Salix* (willow) is recognizable and abundant, but although most species are not separately identifiable, one may presume that the pollen comes from the northern dwarf species, just as the smallest birch pollen probably derives from *Betula nana*. *Hippophae rhamnoides*, the sea buckthorn, is often present in zones I and III in western Europe but seldom occurs in Britain. *Artemisia* is constantly present, and also pollen of *Helianthemum* (the rock rose), but in neither instance is the species certainly known. Pollen of *Thalictrum* (possibly *T. alpinum*), *Rumex*, *Armeria*, *Dryas*, *Galium*, *Ulmaria*, *Campanula*, and a great many more also occurs freely. In the north-west of Ireland, *Empetrum* pollen occurs in such large amounts as to suggest the presence of *Empetrum* heaths, and the species can be recognized as the true *E. nigrum* L., not the more northerly *E. hermaphroditum*. Pollen of *Juniperus* and *Populus* has been identified by some of the more experienced analysts, and the spores of *Selaginella* and *Botrychium* are abundant.

In the Allerød period itself, the park-tundra vegetation was to a varying degree suppressed by the development of closed woodlands, and Iversen's pollen maps of southern Scandinavia for this period indicate that while in northern Denmark and Sweden the woods were of birches, in northern Germany pine forest temporarily prevailed. The new knowledge of the late glacial park-tundra vegetation accords remarkably well with the increasing recognition of the abundant fauna of herbivorous mammals—bison (*Bison bonasus arbusto-tundrarum*), horse, reindeer, and elk (*Alces alces*). It is of the greatest interest that practically all the finds of skeletons or antlers of the giant Irish deer (*Cervus megaceros*) from Ireland have now been shown by Mitchell and Jessen to have come from the chalk marls of the Allerød period. It seems impossible not to link the extinction of this great beast with that extension of the forest which at once reduced its grazing and gave shelter to predators.

This deduction affords an opportunity of commenting on the facility with which animal remains may be referred by pollen analysis to the period of their origin, not merely when found undisturbed *in situ* in deposits, but also whenever an isolated horn core or bone can yield a few cubic millimetres of dried mud for a pollen analysis.

Naturally, the principle applies no less to plant remains. In several instances we have collections of seeds, fruits, and leaves which permit the recognition of numerous species, and their allocation to the late glacial is confirmed essentially by pollen analysis of the deposits from which they come. A large collection of this kind has recently been made at Nazeing, in the Lea valley, a little north of London. Among many features of interest presented by it we may note two: firstly, the presence of many species of plants now behaving in Britain as weeds of cultivation or waste-land plants, and until now regarded as introduced by prehistoric agriculturalists. These include *Galeopsis tetrahit*, *Sonchus asper*, and *Linaria vulgaris*, discoveries which recall the identification of late glacial pollen of the corn-flower (*Centaurea cyanus*) in Denmark and East Anglia, and of the wild parsnip (*Pastinaca sativa*) in Britain.

Secondly, we may note the presence of many species widely outside their present British range, and among them some whose distribution is today strikingly scattered. In this class are fruits of *Potentilla fruticosa*, *Thalictrum alpinum*, *Dryas octopetala*, and *Betula nana*, among others. Even more striking is the presence of considerable amounts of the pollen of Jacob's ladder, *Polemonium caeruleum*, a handsome plant with elaborate pollen easily distinguished from that of other species (see figure 4), and with a present restricted and scattered distribution. There has been a strong tendency to interpret the local and restricted ranges of species such as these in terms of survival *in situ* through at least the last glaciation, but as will be seen from the map (figure 12), *Polemonium* has been found as a fossil so often in Britain that it cannot be doubted that it had a very wide distribution in late glacial times.

Indeed, at this time of open immature and mobile soils, still not stratified by leaching from upper layers and deposition in lower ones, when forest competition was absent, and the North Sea basin was still land, conditions for dispersal must have been remarkably favourable for a very large range of plants, especially those we now regard as weeds and plants of open habitats. In the ensuing post-glacial period, however, the spread of forests and peat mires, and the leaching of soils, all greatly restricted the range of such species. In short, post-glacial events must have been responsible for some, and perhaps many, of the so-called relict distribution ranges hitherto explained as due to per-glacial survival.

INTER-GLACIAL AND OLDER DEPOSITS

One of the outstanding and urgent tasks of pollen analysis is to throw light upon the nature of the British inter-glacial deposits, to co-ordinate them with similar deposits on the European continent and so possibly to assist in the vexed problem of correlating British and extra-British glacial phenomena. There is already some ground for supposing this to be feasible. More than twenty years back, Jessen and Milthers published the results of their intensive investigation of pollen and other fossil material from Denmark and northern Germany, and subsequent investigations have strengthened their main conclusions. They were able to demonstrate, by pollen diagrams for deep lake-deposits, that the climatic vegetational history of each inter-glacial period followed a course essentially similar to that of the post-glacial, but continuing of course into a succeeding glaciation. Nevertheless, certain features appear to have characterized the various inter-glacials; thus, during the last of them, hornbeam (*Carpinus*) came to play such a dominant role in the deciduous woodlands as apparently it had neither done before nor has done since in north-western Europe. When, during recent months, hornbeam pollen was recovered in substantial amounts from organic muds of an inter-glacial gravel terrace in Cambridge, England, this fact pointed a possible reference to the last inter-glacial period. Among the identifications of warmth-demanding species were the fruits of *Naias minor*, a water-plant of central and south-eastern Europe, not known as a living plant in Britain, although known from other inter-glacial deposits here. Wolstedt has recently exhibited a short pollen diagram completed by P. W. Thomson for part of the famous Cromer Forest bed. Jessen and Mitchell have briefly reported on pollen analyses in progress upon Irish inter-glacials, and it is evident that we may expect much information to illuminate this field of inquiry.

There is no need, however, to suppose that pollen analyses must be restricted to the Quaternary period, although before this period the identity of the pollen types encountered becomes less certain, and the aims are correspondingly in somewhat different directions. On the one hand we have the remarkable (and still largely unpublished) work of Simpson on the Tertiary plant beds of western Scotland, in which there has been found a wealth of pollen types referable to genera such as Eucalyptus, and even of the living fossil *Metasequoia* so recently discovered growing in China. These are genera now characteristic of far-distant regions of the globe, and their presence indicates great plant migrations. On the other hand, we have in progress in many parts of the world intensive research upon the pollen and spore content of brown coals of Tertiary age, research aimed in part at discovering methods of correlation and dating. Although many of the types are not referable to living plants, important conclusions nevertheless emerge from their study. We may note that Thomson has been able to show of the lignites of north-western Germany that the parent materials were formed in communities corresponding to the wooded fens and to the great heath-clad sphagnum bogs of post-glacial times, each type exhibiting its own characteristic pollen picture derived from the local vegetation growing upon it during formation.

From Jurassic deposits there has been recovered a pollen grain of undoubted dicotyledonous type—perhaps our earliest evidence of this great group of plants—and, although it may be stretching the term pollen analysis to include it, we must note that spore analysis is a practicable and useful method now employed for characterizing particular seams of coal in our prolific Carboniferous coal measures.

Pollen analysis as a means of Quaternary research has been far more intensively developed in western Europe than elsewhere, but a substantial volume of research has been completed in North America, and enough has been done in New Zealand, Patagonia, and other distant regions to give colour to von Post's vision that planned and co-ordinated research of this kind may ultimately give a global picture of Quaternary climatic changes. There seems a very fair prospect that the radio-carbon dating developed by Libby may supply us with a more direct method of dating fossil organic materials than is afforded by pollen analysis. Should this be so, it would become possible at once to co-ordinate pollen diagrams from distant parts of the world, and correspondingly to accelerate research into many aspects of Quaternary history.

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Flames: their structure and radiation

A. G. GAYDON

Although the study of flames presents many technical difficulties it is rewarded by results of considerable practical and theoretical importance. The mechanism by which carbon is formed in flames is important both to the metallurgist and to the designer of internal combustion engines. The study of the radiation emitted has led to advances in knowledge of the chemical processes involved, and of the way in which energy is transferred between molecules.

Flames may be classified into two general types, those of premixed gases, and those of a combustible gas burning by diffusion in a supporting atmosphere. The most familiar form of the premixed flame is that given by a Bunsen burner. A candle flame is an example of the diffusion flame. With the air-holes of a Bunsen open to give full aeration we see a relatively bright blue-green inner cone and a surrounding sheath or outer cone of a pale blue-violet colour. This is illustrated in figure 4, which shows a flame of ethylene premixed with air.[1] The inner cone is the flame front in which the chemical reactions of the combustion occur. The flame may be regarded as a continuous explosion travelling against the gas stream, and the velocity may be determined approximately by measuring the angle of the cone and the rate at which the unburnt gas mixture is flowing. The flame front is very nearly conical in form but is slightly splayed out near the burner rim, where the flame velocity is reduced by the presence of the cool burner wall; it is slightly rounded at the top, where the velocity is somewhat greater because heat and active radicals are being supplied three-dimensionally from all sides at this point.

If the air supply is reduced a little (figure 5) the flame velocity falls and the inner cone consequently becomes longer. It is also less bright and has a luminous yellow tip, the yellowness being due to radiation from small incandescent particles of carbon. If the air supply is completely stopped (figure 6) the flame becomes yellow, owing to carbon formation, throughout its length, apart from a weak blue-violet region surrounding the base of the flame. This is the typical appearance of a diffusion flame of a hydrocarbon burning in air.

While most premixed flames with which we are familiar show a marked inner cone, this is not an essential property of all flames. The flame of hydrogen with air or oxygen does not show any visible inner cone, nor is there any increase of ultra-violet radiation from the flame front. The appearance of a bright inner cone is most characteristic of organic compounds, although it is also found in other flames, such as oxy-ammonia. In some very hot flames, such as oxy-acetylene, there is a bright mantle surrounding the inner cone when the fuel is in slight excess.

It is possible to separate the inner and outer cones of a flame with a Smithells' separator. In this device the burner is enclosed in a fairly closely fitting tube of glass or quartz which projects an inch or so above the burner tip. By adjustment of gas-flows it is possible to get the inner cone to settle on the inner burner rim, while the outer cone forms on the top of the glass tube, as in figure 7. It should be noted that there is practically no radiation from the region between the two cones, i.e. from the hot interconal gases. Chemical sampling shows that these interconal gases consist mainly of hydrogen, carbon monoxide, water vapour, and nitrogen, the organic compounds being almost completely broken down in the inner cone. The outer cone may thus be identified with the diffusion flame of the hydrogen and carbon monoxide.

An interesting, and still incompletely solved, problem is the mechanism by which carbon is formed in flames. It is of considerable industrial importance, for example in the design of open hearth furnaces and internal combustion engines. In premixed flames, the formation of carbon is quite sensitive to the presence of catalysts; thus Whittingham and the author [1] have shown that one part in a thousand of sulphur trioxide added to the gases in a fully aerated Bunsen flame will cause the flame to turn yellow; sulphur dioxide, on the other hand, reduces the tendency to carbon formation. In diffusion flames, however, catalytic effects are unimportant.

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[1] Colour photography has rather serious limitations when dealing with self-luminous sources. Considerable trouble has been taken to make the colours in the plates as nearly true as possible, but perfect reproduction has not been achieved.

In diffusion flames the mixing processes are relatively slow, and it is unlikely that there is any marked departure from equilibrium conditions. For premixed flames, however, the gases pass through the very thin reaction zone in a time of the order of a hundred-thousandth of a second, or for flames with oxygen in less than a millionth of a second. In these very short times it is probable that the fuel molecules are polymerized by some rapid chain-reaction processes, probably initiated by active free radicals, before breaking down to form solid carbon.

It is obvious that in the flame front the chemical reactions are proceeding so rapidly that it is not possible to take samples or follow the processes by ordinary chemical methods. Some information can be obtained by studying the effects of additives on flame velocity and combustion limits, or by analysing the radiation from the flame itself. We find that in organic flames many chemically unstable free radicals, such as OH, CH, C_2, and HCO, are present in the flame front or inner cone. A review of this aspect has recently been given by Barrow [2], and a more complete treatment of the subject by the author [3]. Existing chemical theories of combustion processes do not make use of, or account for, the presence of many of these radicals (CH, C_2, HCO), yet their radiation is the most characteristic feature of the combustion, and in suitable cases may easily be used empirically to identify the type of combustion occurring.

The mechanism of formation of C_2 and CH radicals in flames is unknown, but it seems at least fairly certain that it is not a very simple one. The bands of C_2 and CH are emitted much more strongly by flames very rich in fuel. It has recently been found by the author and Wolfhard that if, in a flame of a hydrocarbon, the hydrocarbon is partially replaced by some other combustible, e.g. hydrogen or carbon monoxide, in such amount as to keep the mixture at the same strength, then the amount of the C_2 and CH radiation falls off surprisingly rapidly. These results seem to show that the formation of C_2 and CH is not due to direct simple reaction between fuel and oxygen.

Pannetier and the author [4] have found that a flame of dry cyanogen burning with dry oxygen emits the C_2 and CN bands very strongly, but that the addition of a little moisture or hydrogen causes a remarkable decrease in the C_2 radiation; emission from CH radicals then occurs, suggesting that C_2 may react with OH or H_2 to form CH.

A striking result is obtained by adding a little nitric oxide to a flame. In many cases this produces a yellowish-green coloration due to the reaction:

$$NO + O = NO_2 + \text{radiation.}$$

This serves as a qualitative test for the presence of atomic oxygen in the flame. Figure 7 shows an ethylene-air flame burning in a Smithells' separator. Figure 8 shows the same flame with a little nitric oxide added. The inner cone is more violet, owing to emission of radiation from CN radicals, and the outer cone has changed to a greenish shade, owing to the presence of atomic oxygen in that region. The greenish shade is absent from the interconal gases, and it can be shown that its characteristic continuous spectrum is not emitted from the inner cone. This shows the absence of appreciable quantities of atomic oxygen during the initial combustion of the hydrocarbon.

In flames at atmospheric pressure, the flame front in which the main chemical reactions occur (corresponding roughly to the luminous inner cone) is only of the order of a fiftieth of a millimetre thick, and since the flame is usually roughly conical in form it is not possible to study the radiation from the flame front in any detail. In recent work the author and Wolfhard [5] have been able to learn something of the detailed structure of the flame front by running flames at very low pressure. The flame is enclosed in a large Pyrex vessel which is continuously evacuated, a burner of large diameter being used. The flame is viewed through a quartz window. It has been found possible to maintain steady flames at pressures below a hundredth of an atmosphere (for oxy-acetylene a pressure of 0·9 mm mercury has been reached). In these flames the flame front is much thicker—it may be of the order of a centimetre or so—and the flame can be made flat, so that the radiations from the base and top of the reaction zone can be studied separately. For hydrocarbons burning with oxygen, such as the oxy-acetylene flame shown in figure 2, the blue-green flame has a greenish base and a more violet top. By projecting an image of the flame on to the slit of a spectrograph we find that the spectrum (figure 1) shows the yellow-green, green, and blue-green bands of C_2 most strongly at the base of the flame, while the blue-violet and violet bands of CH are emitted rather higher in the flame, causing the violet colour at the top. One might have expected that in the oxidation of a hydrocarbon CH would be formed before C_2, but the reverse appears to happen.

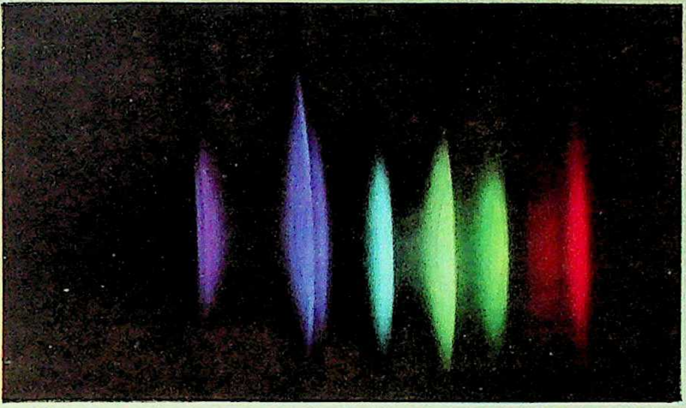


FIGURE 1 – *Spectrum of oxy-acetylene flame at low pressure, showing violet and blue-violet bands of CH higher than blue-green, green, and yellow-green bands of C_2.*

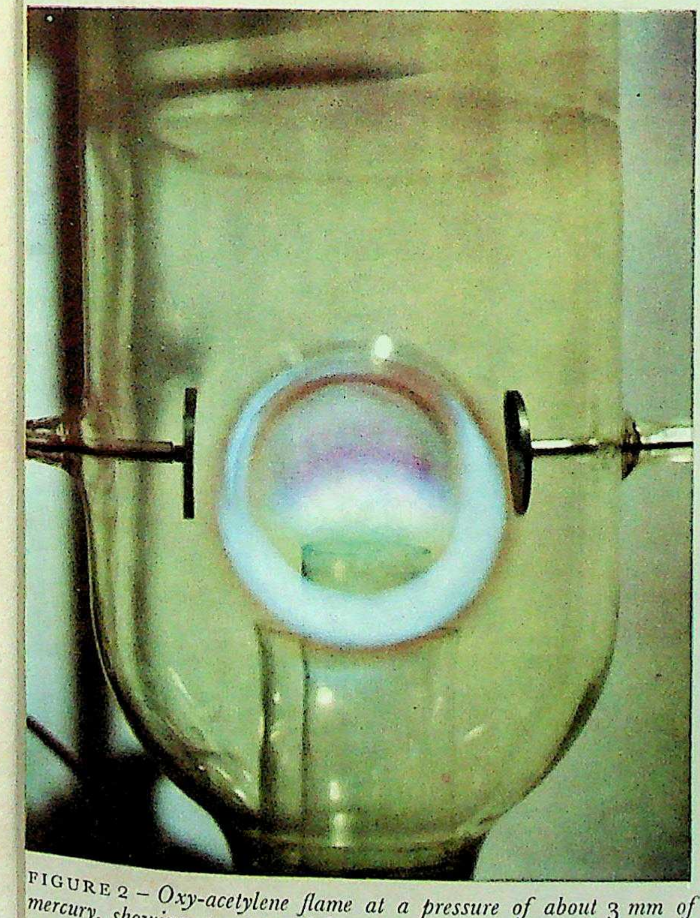


FIGURE 2 – *Oxy-acetylene flame at a pressure of about 3 mm of mercury, showing structure of flame front.*

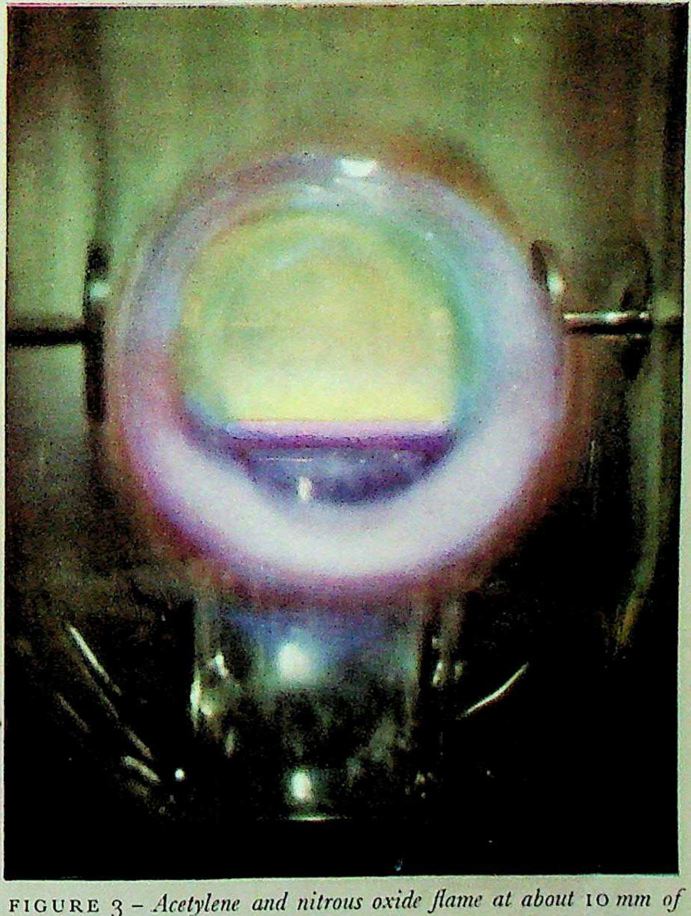
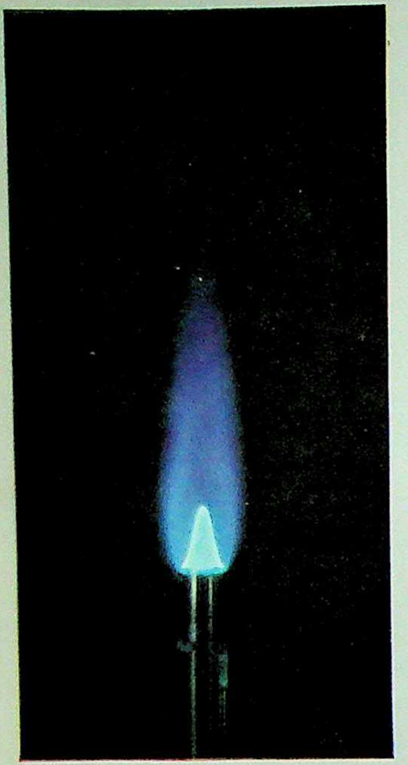
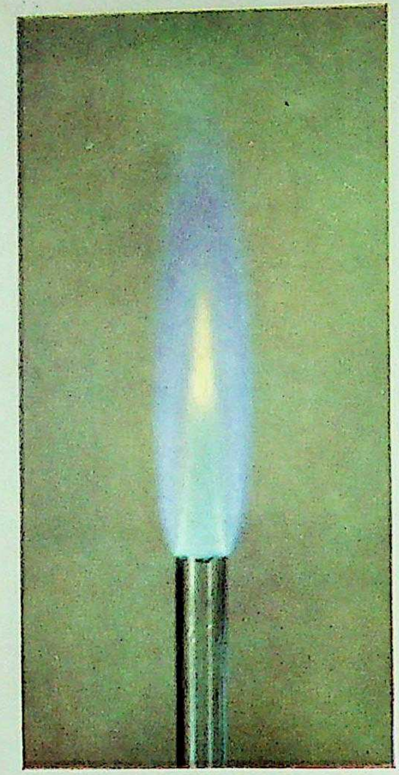


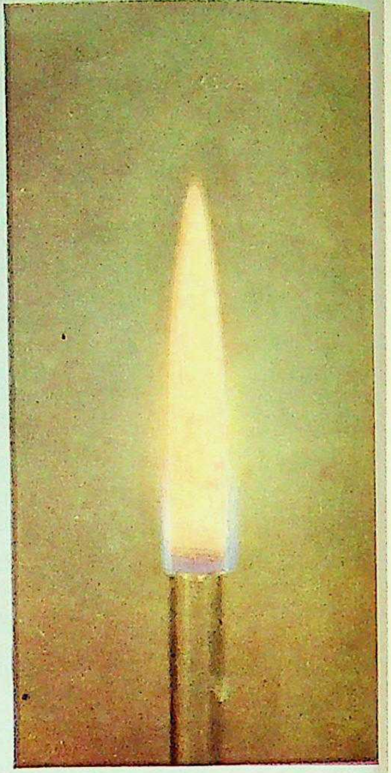
FIGURE 3 – *Acetylene and nitrous oxide flame at about 10 mm of mercury.*



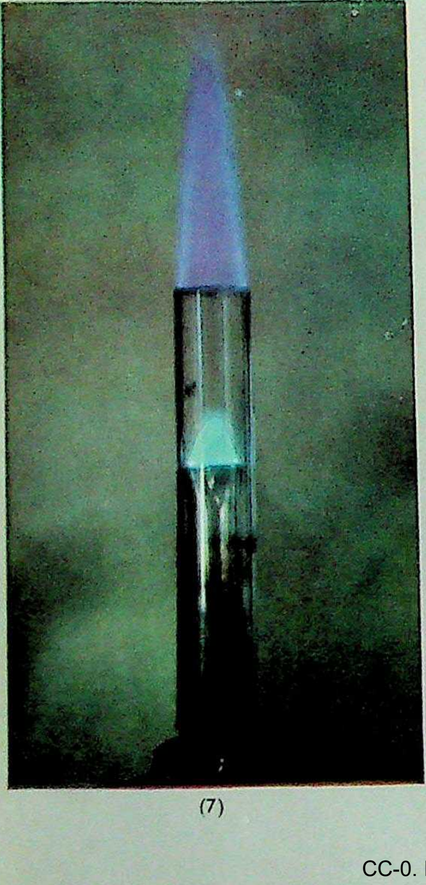
(4)



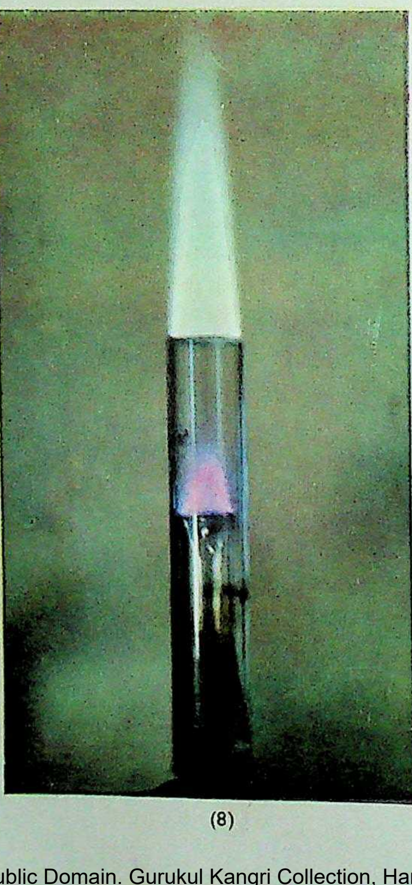
(5)



(6)



(7)



(8)

FIGURE 4 – *Premixed flame of ethylene and air; full aeration.*

FIGURE 5 – *Premixed ethylene-ai flame; aeration reduced.*

FIGURE 6 – *Ethylene-air. Diffusio flame.*

FIGURE 7 – *Ethylene-air flame o Smithells' separator.*

FIGURE 8 – *The effect of addin nitric oxide to an ethylene-air flame.*

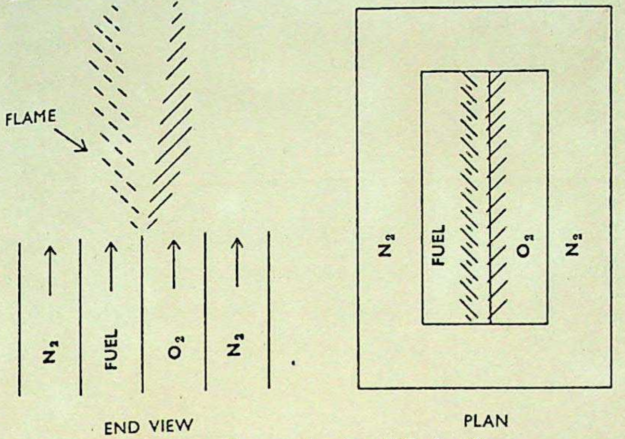


FIGURE 9 – *Burner for flat diffusion flames.*

Figure 3 shows an interesting flame of acetylene mixed with nitrous oxide. This has a rather thin, intensely bright, violet reaction zone, the emission from which is due mostly to CN radicals, with a greenish-yellow glow above, which is probably due to reaction between nitric oxide and atomic oxygen.

The structure of diffusion flames can also be examined in detail, and Wolfhard and Parker [6] have designed a burner for this purpose (figure 9). The central part is rectangular in form and is divided into two, with fuel passing up one section and oxygen up the other, so that combustion takes place along the straight division. This rectangular burner is enclosed in a second rectangular jacket up which there is a flow of nitrogen to isolate the flame from the surrounding air. The flame can then be studied edge on. For hydrocarbons, such as ethylene or methane, there is a bright yellow region of flame on the fuel side, due to carbon formation. This is separated by a dark region from a bluish zone on the oxygen side. This bluish zone shows emission from C_2, CH, and OH radicals, and on the oxygen side of the zone there is also some emission of the Schumann-Runge bands of oxygen itself. It may be noted that here the C_2 appears to be formed after, not before, the solid carbon. With this type of flame it is possible both to study the emission spectrum and to record the absorption. Hot oxygen itself shows absorption in the far ultra-violet, just within the range of quartz instruments, and by choosing a suitable fuel, such as benzene, the absorption of the fuel also can be followed. It is found, rather surprisingly at first sight, that there is no appreciable contact between oxygen and fuel, the fuel being decomposed thermally to hydrogen, carbon, and other products before it reaches the oxygen. The region just on the fuel side of the yellow carbon-formation zone shows continuous absorption in the ultra-violet; this may be due to the polymerization of fuel which occurs before carbon formation.

Radiation gives information about physical as well as chemical processes. The diffusion of OH radicals back against the gas stream can be followed by means of absorption spectra, and results suggest the important role of diffusion in flame propagation. By detailed examination of band spectra we can determine the average amounts of rotational and vibrational energy possessed by the emitting molecules, and by studying the Doppler broadening of the spectrum lines we may in favourable cases even get at the average translational energies of the molecules. This is yielding some information about the processes by which energy is transferred to and from molecules. In many cases the amount of rotational energy present in the emitting molecules corresponds to very high temperatures (5000–10,000° C) and can be due only to the excitation resulting from the chemical processes.

Besides the natural emission from the flame, it is found [7] that when suitable metals are added to the flame gases, then the spectra of these metals are much more strongly and fully excited in the flame front than in the region just above or in the outer cone. This occurs for many organic flames and a few inorganic flames, such as oxy-ammonia, but not for hydrogen, carbon monoxide, or even some flames which do show inner cones, such as those of formaldehyde and carbon disulphide. This effect, which has only recently been discovered, has not yet been explained. There is also evidence that the ionization in flames, especially in the inner cone, is higher than would be expected on thermal grounds.

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Hormones and the metamorphosis of insects

V. B. WIGGLESWORTH

'Those strange and mystical transmigrations that I have observed in Silk-worms,' wrote Sir Thomas Browne, 'turned my Philosophy into Divinity. There is in these works of nature, which seem to puzzle reason, something Divine, and hath more in it than the eye of a common spectator doth discover.' Who, indeed, he says, can fail to wonder 'at the operation of two Souls in those little Bodies'?

The contemplation of the metamorphosis of insects has always evoked feelings of mystery. When regarded more closely through the eyes of the anatomist and the experimental biologist, the superficial mystery is dispelled—to be replaced by deeper mysteries.

Even in that extreme example, metamorphosis in the Lepidoptera, where the caterpillar is transformed into the chrysalis and the butterfly, the rudiments of the organs of the adult or imago—the wings and legs and so forth—are already present in the young larva as clusters of undifferentiated cells, the so-called imaginal disks. Throughout the larval life of these insects (the 'endopterygote' insects) the wing germs grow inwards, and do not become apparent until they are everted at pupation.

The fact remains, however, that the strictly adult structures play no functional part in larval life. Whereas the form of the caterpillar becomes fully differentiated before it hatches from the egg, the adult insect persists in an embryonic state until the growth of the caterpillar is complete and metamorphosis takes place. Indeed, the caterpillar is not a walking embryo, as some authors have contended, but a fully differentiated organism which contains within it, in an embryonic state, the adult butterfly. Metamorphosis consists in the dissolution of the organism of the caterpillar and the simultaneous differentiation and realization of the latent organism of the butterfly which supersedes it.

In the development of animals, the stage of visible differentiation of the parts is preceded by a stage of 'determination,' at which, although all parts outwardly look alike, each is in fact already committed or determined to form some particular component of the organism that is to be produced. Development is then said to have reached the mosaic stage. Determination of the main parts of the insect body occurs very early in the development of the egg. In some insects, the fruit fly *Drosophila* [4] for example, the mosaic state is already attained in the germ plasma on the surface of the egg at the time of laying; that is, before the single nucleus of the egg has even started to divide. In other insects this may not happen until after the germ band has formed. If, when the mosaic state is reached, a part of the determined area is destroyed by burning or by irradiation with ultra-violet light, the corresponding part of the insect will be lacking when visible differentiation and development are complete.

The interesting fact about these insects is that, even at this early stage of development, the larval organism and the adult organism are distinct. Elimination of restricted areas of the newly laid egg of *Drosophila* results in corresponding deficiencies in the resulting larva—but the adult fly, when it appears, is perfectly normal. At this stage the egg is a mosaic in respect of larval characters, but is still undetermined in respect of the adult characters. But within seven hours after laying, imaginal determination has taken place; the egg is now a mosaic in respect of adult characters also, and injuries to restricted areas at this time become apparent in the adult fly. Indeed, if they affect organs, such as legs or wings, that are not present in the larva, the results of these injuries are not visible at all until after metamorphosis. The same thing is seen in the clothes-moth *Tineola* [5]; by irradiation at the appropriate moment it is sometimes possible to obtain a clothes-moth with normal limbs developing from a larva in which one or more legs were completely absent.

Thus, metamorphosis consists in the realization of all those adult or imaginal characters which remain latent throughout larval life; the physiological

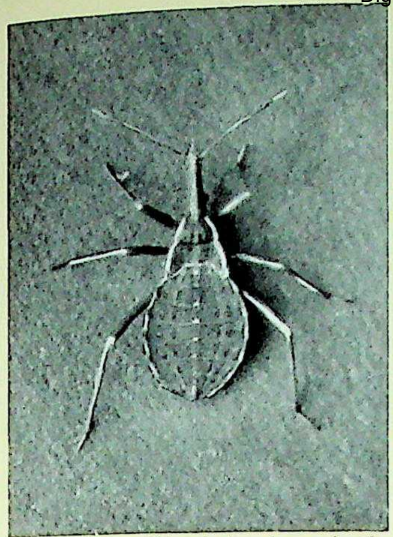


FIGURE 1 – Rhodnius *larva in the 4th stage.* (× 4)

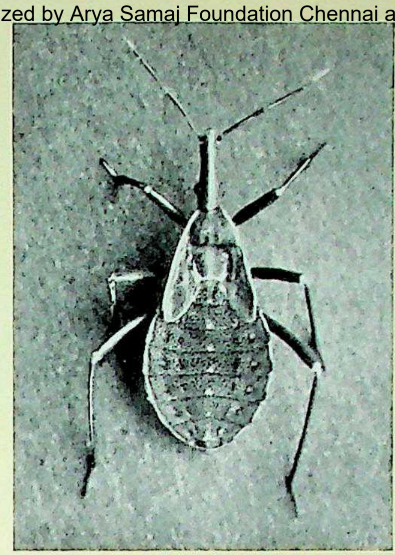


FIGURE 2 – Rhodnius *larva in the 5th stage.* (× 3)

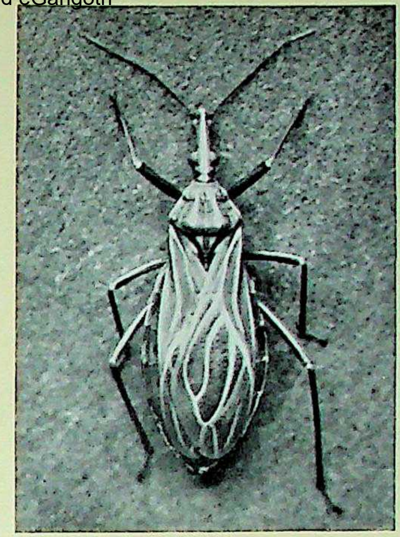


FIGURE 3 – Rhodnius *adult with fully developed wings after metamorphosis from the 5th-stage larva.* (× 2·5)

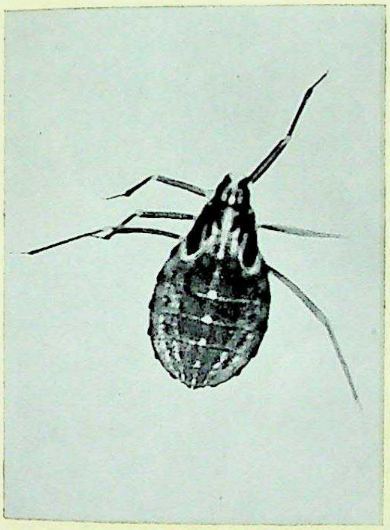


FIGURE 4 – *5th-stage larva of* Rhodnius *still alive more than eleven months after decapitation.* (× 2)

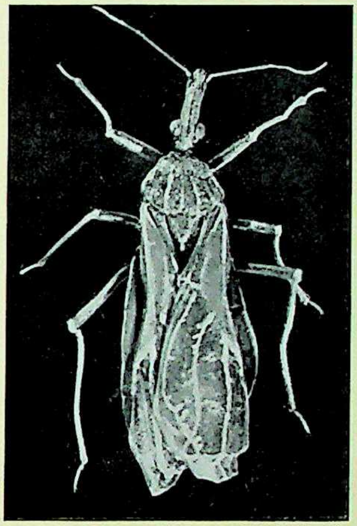


FIGURE 5 – *Giant adult of* Rhodnius *resulting from the metamorphosis of a 6th-stage larva.* (× 2)

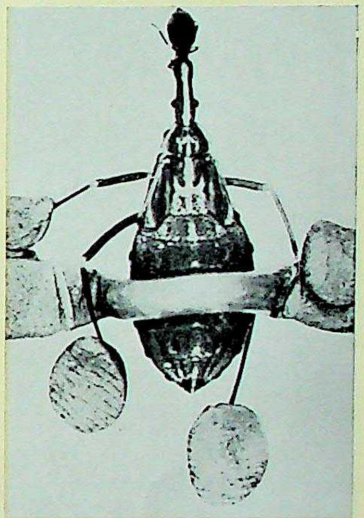


FIGURE 6 – *1st-stage* Rhodnius *joined by neck to 5th-stage larva, causing dwarf adult.* (× 3)

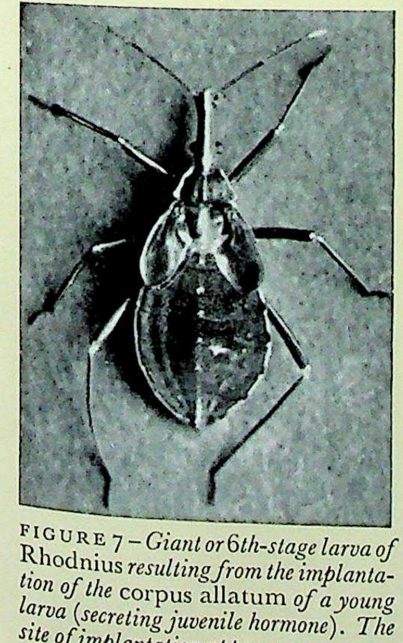


FIGURE 7 – *Giant or 6th-stage larva of* Rhodnius *resulting from the implantation of the* corpus allatum *of a young larva (secreting juvenile hormone). The site of implantation appears as a scar on the abdomen.* (× 2·5)

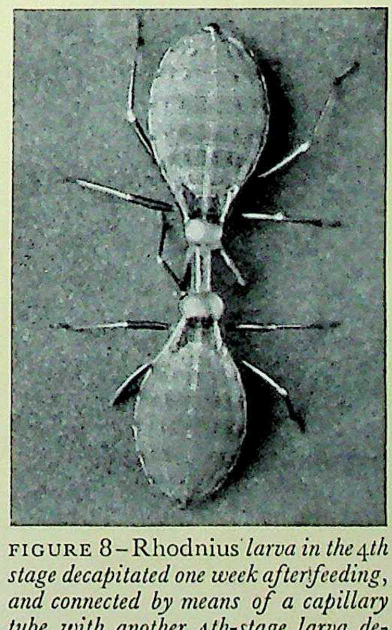


FIGURE 8 – Rhodnius *larva in the 4th stage decapitated one week after feeding, and connected by means of a capillary tube with another 4th-stage larva decapitated four days after feeding. The moulting hormone from the first insect causes the second to moult.* (× 3)

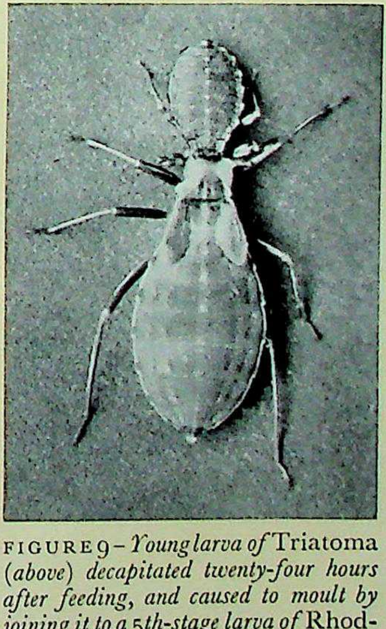


FIGURE 9 – *Young larva of* Triatoma *(above) decapitated twenty-four hours after feeding, and caused to moult by joining it to a 5th-stage larva of* Rhodnius *decapitated ten days after feeding.* (× 3)

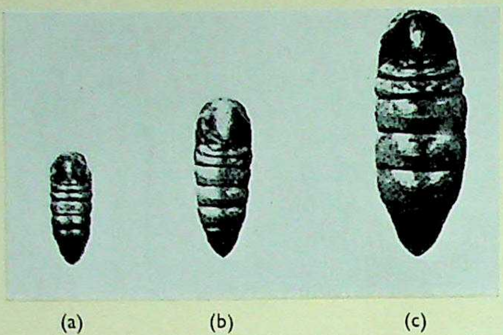


FIGURE 10 – *Pupae of the silkworm:* (a) *from larvae in which the* corpora allata *were extirpated in the third stage;* (b) *from larvae similarly treated in the fourth stage;* (c) *from normal larvae pupating after the fifth stage.* (*After Fukuda.*) (× 1·5)

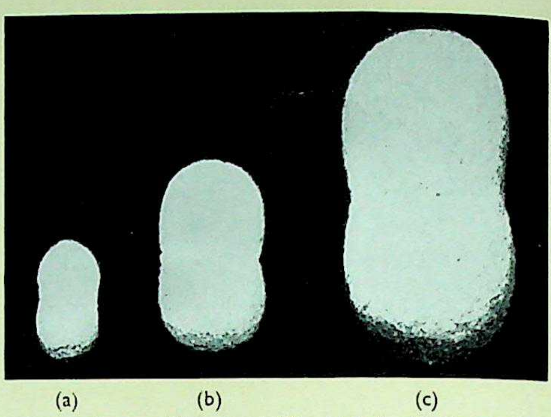


FIGURE 11 – *Cocoons of silk containing the three pupae shown in figure* 10. (*After Fukuda.*) (× 1·3)

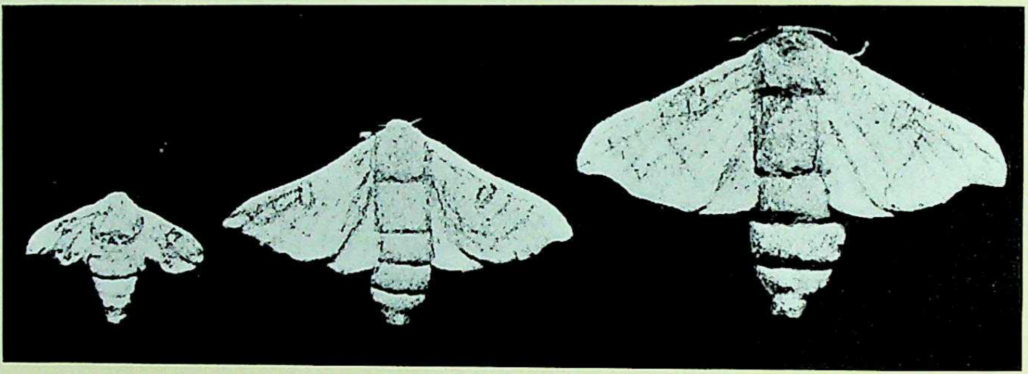
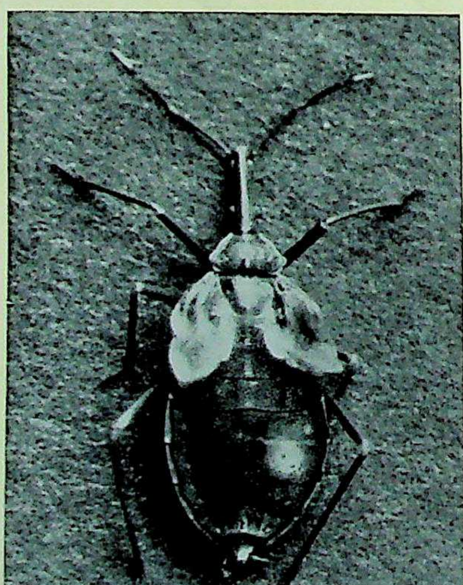
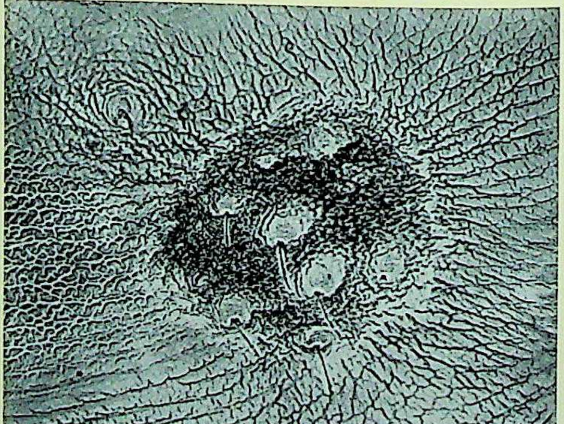


FIGURE 12 – *Silkmoths derived from the three pupae shown in figure* 10. (*After Fukuda.*) (× 1·5)

FIGURE 13 (*left*) – Rhodnius *with characters intermediate between larva and adult produced by implanting* corpus allatum *of young larva into the abdomen of 5th-stage larva* (cf. *figure* 7). (× 3)

FIGURE 14 (*below*) – *Cuticle of the abdomen of an adult* Rhodnius *which had been treated during the 5th stage like the insects shown in figures 7 and 13. It has turned into a normal adult, but there is a tiny patch of cuticle of larval type, less than 1 mm in diameter, overlying the site of implantation of the* corpus allatum. (× 65)





study of metamorphosis consists in the analysis of the factors by which the manifestation of these imaginal characters is controlled.

Many diverse hypotheses have been put forward in the past; but in recent years evidence has accumulated that control is exercised by means of hormones. For the purpose of experiment it proved convenient, in the first instance, to use a hemimetabolic insect; that is, an insect which does not show the extreme degree of transformation from caterpillar to butterfly, but one in which the young stages are not very unlike the adult, and in which metamorphosis consists in the development of wings and genital organs and other structural changes, accomplished without the necessity for an intermediate pupal stage.

The blood-sucking South American bug *Rhodnius*, a creature about two centimetres in length when fully grown, has proved a most useful experimental animal [8, 9, 10, 11]. All insects grow by undergoing a series of moults, during which the epidermis detaches itself from the old cuticle, lays down a new and larger cuticle, and then casts off the old. Like the small bed-bug *Cimex*, *Rhodnius* moults five times; in each of its moulting stages it requires only one gigantic meal of blood. It is at the fifth moult that it undergoes metamorphosis and becomes adult (figures 1–3).

Moulting in *Rhodnius* is preceded by growth, reorganization, and the deposition of the cuticle for the next stage. This whole elaborate process is set in motion by a secretion from certain large modified nerve cells (neurosecretory cells) situated in the dorsal surface of the brain. If the bug is decapitated within one day after its great meal of blood, it fails to moult—although such headless bugs have remained alive for more than a year (figure 4). If, however, the region of the brain containing the secretory cells is transplanted into the abdomen of one of these decapitated insects it will duly moult; and, surprisingly enough, even if it is a young insect at an early stage of development, it will undergo metamorphosis and develop into a diminutive adult. We shall come back to this matter later.

Thus the brain appears to secrete a moulting hormone. In *Rhodnius* this has been supposed to act directly upon the growing organs, but in the caterpillars and chrysalides of moths the process is more complicated. The pupal brain of the silkmoth [13] contains two groups of cells, apparently producing two different secretions, both of which must be present if moulting is to occur. These secretions do not act directly upon the tissues but upon another secretory organ, the prothoracic gland, which in turn produces the secretion that is necessary for growth and moulting. The nature of these substances is not known. There are demonstrable changes in the blood of insects at the time of moulting and pupation, e.g. increases in the amounts of cytochrome oxidase and cytochrome C in the pupae of the large silkmoths [13], and the activation of tyrosinase in the blood of pupating larvae of blowflies [2]. Whether any of these substances is to be identified with the hormone itself, or whether they are merely to be counted among the consequences of its activity, remains to be decided.

The implantation of the cells of the brain, which produce the moulting hormone, into the abdomen of the decapitated *Rhodnius*, results, as we have seen, in the occurrence of metamorphosis —even in the young insect whose growth is far from complete. This result suggests that the head produces a second factor which normally prevents metamorphosis in the young stages. That such a factor exists has been proved. It has been termed the juvenile hormone, and it is secreted by a special gland of internal secretion named the *corpus allatum*. The *corpus allatum* lies just behind the brain; it shows some remarkable resemblances to the glandular part of the pituitary gland in mammals.

Rhodnius, as we have seen, has five larval stages before it becomes adult. If the *corpus allatum* is removed from one of the young stages and implanted into the abdomen of a fifth-stage larva, when this moults it turns into a giant or sixth-stage larva instead of undergoing metamorphosis to an adult (figure 7). Even a seventh-stage larva has been produced in this way, and some of the sixth-stage larvae have transformed successfully into giant adults (figure 5, and *cf.* figure 6).

Conversely, removal of the head of a young *Rhodnius* when moulting is just beginning causes the body to undergo a precocious metamorphosis. It has not been possible to remove the *corpus allatum* in the living *Rhodnius* without undue injury to the head and brain. This has, however, proved possible in other insects, and the results obtained in *Rhodnius* have been amply confirmed. Stick-insects, *Dixippus* [6], treated in this way begin to lay eggs while still quite small. Cockroaches [7] become prematurely adult. Silkworms [1, 3] turn into tiny pupae which give rise to tiny moths (figures 10–12).

The juvenile hormone is secreted throughout the first four larval stages of *Rhodnius*. During the fifth stage it is no longer secreted; the *corpus allatum* of the fifth stage implanted into the abdomen of another fifth stage does not prevent metamorphosis. In the adult insect, however, this hormone is once more produced. Here it is necessary for the ripening of the eggs. If the adult female is decapitated after feeding, no eggs are developed; they are developed normally if the *corpus allatum* is implanted in the abdomen. If the *corpus allatum* of the mature adult is transferred to the abdomen of the fifth-stage larva, metamorphosis is prevented and a sixth stage is produced.

It is evident that these hormones serve only to control the manifestation of characters that are latent within the cells. It is therefore not surprising to find that they are not limited in their action to the insect species from which they have been derived. The blood of a moulting *Rhodnius* will induce moulting in a decapitated nymph of the related genus *Triatoma* (figure 9, and *cf.* figure 8), or even in the bed-bug *Cimex*. The fifth-stage larva of the bed-bug can be prevented from becoming adult if it is transfused with blood from a young larva of *Rhodnius* containing the juvenile hormone.

Normal development of an insect, with the restraint of metamorphosis until growth is complete, and then, at the appropriate moment, the activation of imaginal differentiation, clearly demands a very nice timing of events. The hormones must be released at the correct time and in the correct amounts. If these conditions are not satisfied, as may happen, for example, in some experiments when a *corpus allatum* from a young *Rhodnius* is transplanted into a fifth-stage larva, and the amount of juvenile hormone present is too small or is produced too late, metamorphosis is incomplete, and creatures intermediate between larvae and adults are produced (figures 13, 14). Errors of this kind are not uncommon in nature. Caterpillars with wing lobes and antennae like half-formed pupae may occur; or pupae may have parts of the body resembling larvae. Such abnormalities are most liable to appear in hybrids resulting from the crossing of different species. There can be little doubt that they result from errors in the timing or the concentration of hormone secretions.

It would seem that the cells of the young insect contain two systems, one capable of producing the adult insect, the other producing the larval insect. In the presence of the moulting hormone alone, the adult system is activated and metamorphosis occurs. In the presence of both moulting hormone and juvenile hormone, the larval system is activated and metamorphosis is suppressed. Or perhaps we have to do with a single system whose activities are modified in alternative directions depending on the presence or absence of the juvenile hormone. In the last analysis, the nature of the constituent elements, and the mode of interaction between the hormones and the potential organism latent in the tissue cells, are biochemical problems. For the moment we can define them only in biological terms.

Once the insect has reached the adult state it does not moult again, save in the most primitive forms. The adult *Rhodnius* can be induced to do so if it is joined to a young moulting insect so that the blood flows from one to the other. If at the same time it is provided with a supply of juvenile hormone by the implantation of *corpora allata*, it develops on its abdomen a type of cuticle which shows unmistakable larval characters. There has been a partial reversal of metamorphosis, a partial recovery of youth.

The future of this subject clearly lies with the chemist. It should not prove an insuperable task to discover the nature of the growth-controlling hormones of insects, and to define the conditions of their action. To discover the nature of the substrate upon which they act, the integrated germ of the organism carried by the living cells [12], is a problem that touches upon the nature of life itself, and may well tax the ingenuity of the biochemist for some time to come.

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The transfer of antibodies across the placenta

R. M. CALMAN and JOHN MURRAY

The reality of the transfer of antibodies from mother to foetus has been recognized for nearly half a century; it plays a decisive role in certain very serious diseases peculiar to newborn infants. The mechanism by which it is effected was, however, obscure, because it is clearly not simple diffusion. In this article the authors discuss the hypothesis that the antibody is not transferred complete and that there are other routes than direct transmission through the placenta. Ingenious diagrams illustrate methods of transfer suggested in the text.

The animal organism, in order to withstand the invading forces of nature, has the power to mobilize its defences to combat the introduction of substances foreign to its tissues. One of the mechanisms by which this is contrived is the creation of particular globulins[1] called antibodies, specific for such foreign materials. Any substance is said to be antigenic if on injection into an animal it calls forth in that animal the formation of antibodies. This is an immune response, and is the well-known principle which forms the basis of immunology. It is upon the natural immunity derived from contact with minimal doses of infective materials that the animal in the wild is able to build up a resistance to disease.

It has long been recognized that the infant derives from its mother some degree of immunity to certain diseases, which appears to be passive in nature; that is to say, it tends to disappear comparatively rapidly in the same way as does passive immunity in the adult, in contrast to the relatively permanent active immunity produced by stimulation of the individual's own tissues.

The origin of this immunity varies in the different species of mammals. In some it is obtained through the colostrum after birth, whereas in others it is obtained *in utero*.

TABLE I

Species	In utero	Via *colostrum*
Man	+	−
Rats and mice	+	+
Other rodents	+	−
Ungulates	−	+

It is with this latter group, which includes humans, that we are at present concerned.

The earliest attempts to tackle the problem of placental transmission are those recorded by Cowper, who in 1698 passed metallic mercury into the maternal circulation and was able to demonstrate globules of the metal in the foetal circulation. These transfers were subsequently shown to be due to rupture of placental capillaries.

It was not, however, until the late nineteenth century, as a result of the discoveries of Ehrlich and others on antibodies, that workers turned their attention to the problems of naturally occurring immunity in the newborn. Shortly afterwards, von Behring and his colleagues expressed the view that antibodies would pass the placental barrier only if it had been previously damaged. It was thought that the passage of antibodies through the placenta was impossible, on account of their relatively great molecular size and the difficulty with which they diffused through membranes.

This idea received great support in 1902 from the work of Ascoli, who showed that foreign proteins did not pass the placenta. The results described by Lochead [1] from Edinburgh in 1907, however, were not entirely confirmatory. He injected egg albumin into the veins of pregnant rabbits and found this substance in the foetal blood, as tested by a precipitin technique; ox serum, however, was not transferred under similar conditions. He concluded from his experiments that the mechanism of placental transmission was similar to the secretion of ductless glands, and that it was not a question of a simple filtration, but a process involving the special functions of a living cell.

These results would require confirmation, but his conclusion should be reconsidered in view of the very recent work of Brambell.

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[1] For brevity, when the word globulin is used in the text and diagrams in relation to antibody, it should be understood that the gamma globulin fraction only is intended.

From this point, the picture has been largely coloured by the filtration hypothesis. The papers of Halben and Landsteiner, Schumacher, Römer and Polano [2], together with the studies of Grosser, are all influenced by this view. It is interesting that Polano in his detailed review of the subject in 1904 showed the transfer of passive immunity from mother to child. For these experiments he used tetanus antitoxin prepared in the horse. This, in the light of more recent work, introduced a complication.

The careful anatomical work of Grosser [3, 4] separated placentae of animals into groups according to the number of cell layers dividing the maternal and foetal circulation.

TABLE II

Placental types	*Species*
Pl. epithelio chorialis ..	Pig Horse
Pl. syndesmo chorialis ..	Ruminants (in part)
Pl. endothelio chorialis ..	Beasts of prey
Pl. haemo chorialis ..	Rodents Insectivores (in part) Bats (in part) Apes Man

It was a natural conclusion that these differences between the placentae in the various species might be correlated with the differences in placental permeability to substances of varying molecular size. This work was vigorously pursued by Shimidzu, who classified placental transmission of dyes in terms of their diffusibility in gelatine.

The filtration hypothesis demanded that passage of substances across the placenta should be governed by simple diffusion and osmosis. This was first disputed by Rivkin, who, in a personal communication quoted by Needham [5], suggested that while the bloods must be isotonic, they need not be homotonic.

Needham, in his work on chemical embryology, reviewed the literature of placental transmission and tabulated the results. The table was designed to show the relationship between molecular size and the anatomical barrier. He upholds the views of Rivkin, quoted above, and contends that the importance of Grosser's work was neglected by Wislocki, who thinks that the anatomical differences are of less importance than physiological ones. Needham's table unfortunately appears in some cases to rest on work which is now open to question.

Table III includes only those authors who have recorded the relative levels of antibodies in the human mother and child.

Among the many other workers who have described transmission of antibodies, Debré, Ramon, *et al.* (1930) reported six cases where the mother was passively immunized against tetanus, in five of which they were able to find the antibody in the child; on the whole, the level was lower than in the mother. Their paper was of further interest in that they demonstrated antitoxin in the colostrum in the same five cases.

As will be seen from Table III, later workers, such as Liebling and Schmitz [6], and Bryce and Burnet, report higher levels for diphtheria and staphylococcal antitoxins respectively, but did not attach significance to these results. In fact, one is left with the impression that higher levels of antibody in the cord blood were regarded with scepticism by the authors themselves, because they could not be fitted into the current hypothesis.

At this point it is interesting to note that many

TABLE III

Author	*Antibody level*	*Antibody used*
Polano	(1904) Infant less than mother	Diphtheria
Polano	(1904) Infant less than mother	Tetanus
Stáubli	(1903) Infant less than mother	Typhoid
Schumacher	(1901) Infant less than mother	Typhoid
Wohlgemuth and Massone	(1911) Infant less than mother	Staphylococcal
Ten Broeck and Bauer	(1923) Infant equal to mother	Tetanus
Etienne	(1899) Infant higher than mother	Typhoid
Liebling and Schmitz	(1943) Infant often higher than mother ..	Diphtheria
Bryce and Burnet	(1932) Infant often higher than mother ..	Staphylococcal
Barr, Glenny, and Randall	(1949) Infant often higher than mother ..	Diphtheria
Murray, Calman, and Lepine	(1950) Infant often higher than mother ..	Staphylococcal

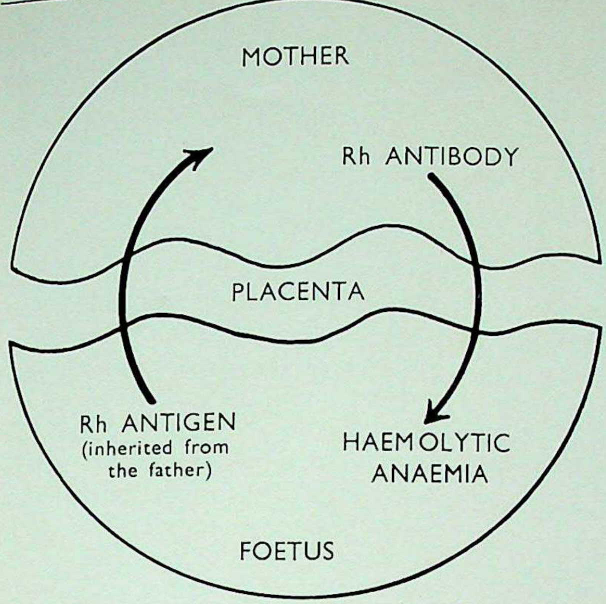
MOTHER
Rh ANTIBODY
PLACENTA
Rh ANTIGEN (inherited from the father)
HAEMOLYTIC ANAEMIA
FOETUS

FIGURE 1 – *Illustration of the way in which iso-immunization occurs in pregnancy.*

of these workers reported the presence of appreciable quantities of antitoxin in the amniotic fluid. We have ourselves confirmed this finding in the case of staphylococcal antihaemolysin in a series of unpublished experiments. The significance of these observations will be described later, in relation to the work of Brambell and his colleagues.

The simple filtration hypothesis has been further disputed by Timmerman (1931), who demonstrated a difference in the passage of typhoid O and H agglutinins from mother to child. He found that the H agglutinin passed the placenta in a considerable number of cases, whereas the O agglutinin was scarcely transmitted at all. He took the view that these results showed a selective mechanism dependent upon the living cell. In the same communication he also reported that the O agglutinins were concentrated more strongly than the H agglutinins in the colostrum.

For some years before the second world war, unusual antibodies had been found in the sera of multiparous women. These antibodies were capable of agglutinating the erythrocytes of many people, including those of the husbands, without any relation to the accepted Landsteiner blood-group system. The discovery of the Rhesus factor in 1940 by Landsteiner and Wiener [7] in their search for further blood-group antigens enabled Levine [8] and his colleagues in 1941 to link the findings of unusual maternal antibodies with the Rh factor, and to identify the cause of haemolytic disease of the newborn.

These workers found in over 90 per cent. of cases that iso-immunization to the Rh factor was responsible for this disease, which covers a wide range of clinical appearances, dependent upon the severity of the disease. Thus, mildly affected babies show only slight anaemia, moderate cases a severe anaemia and perhaps marked jaundice, while more severe cases may die at birth or be stillborn. In the extreme manifestations of the disease, the foetus may even die during the second half of its intra-uterine life.

The mechanism by which this disease occurs is demonstrated diagrammatically in figure 1, where the foetus is shown to inherit the offending antigen from the father. The mode of inheritance has been proved to fit Mendelian principles. It can be seen from the accompanying figure that the complete cycle of the disease depends upon foetal antigen reaching the mother, and maternal antibody reaching the foetus.

During the ensuing years it has been shown that almost all cases of haemolytic disease of the foetus in the human are caused by Rh immunization. There is, however, not just one Rh antigen, but a complicated system of Rh antigens, all of which are antigenic for those who lack them. Discoveries in this field followed rapidly one upon the other in a spate of writings, so that R. A. Fisher [9] in 1944 was able to synthesize the findings of the Cambridge workers into a remarkable genetical scheme. The scheme proposed was all the more remarkable since at that time it postulated the existence of genes as yet undiscovered. All Fisher's postulates have since been verified experimentally.

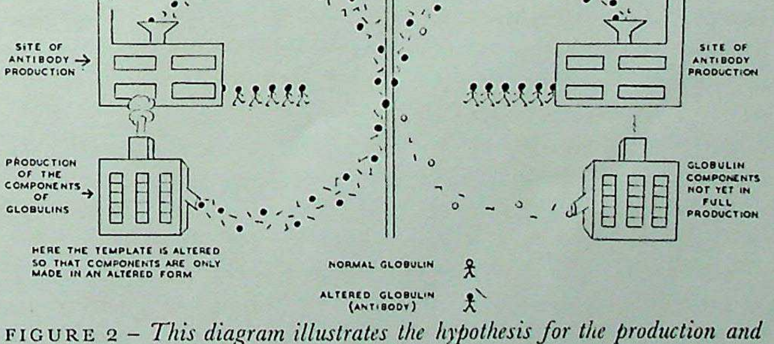
IMMUNE MOTHER
PLACENTAL BARRIER
FOETUS
SITE OF ANTIBODY PRODUCTION →
SITE OF ANTIBODY PRODUCTION
PRODUCTION OF THE COMPONENTS OF GLOBULINS →
GLOBULIN COMPONENTS NOT YET IN FULL PRODUCTION
HERE THE TEMPLATE IS ALTERED SO THAT COMPONENTS ARE ONLY MADE IN AN ALTERED FORM
NORMAL GLOBULIN
ALTERED GLOBULIN (ANTIBODY)

FIGURE 2 – *This diagram illustrates the hypothesis for the production and transfer of antibodies from mother to foetus.*

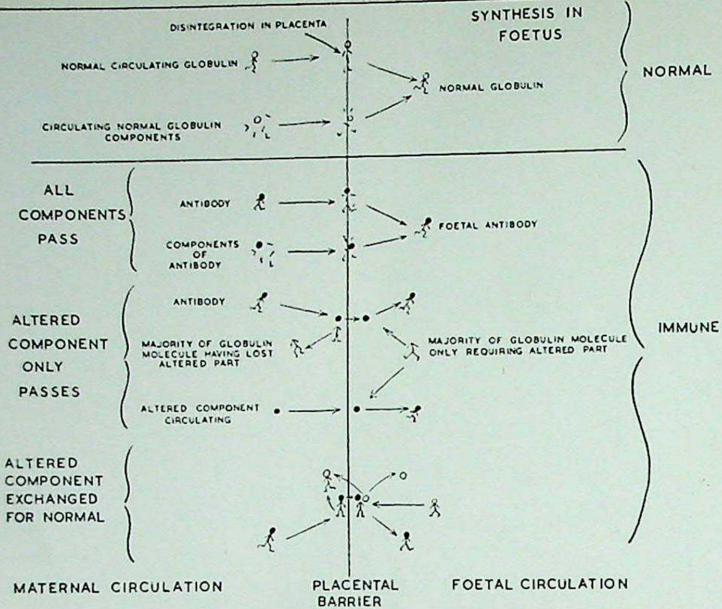
DISINTEGRATION IN PLACENTA
SYNTHESIS IN FOETUS
NORMAL CIRCULATING GLOBULIN
NORMAL GLOBULIN
NORMAL
CIRCULATING NORMAL GLOBULIN COMPONENTS
ALL COMPONENTS PASS
ANTIBODY
FOETAL ANTIBODY
COMPONENTS OF ANTIBODY
ANTIBODY
ALTERED COMPONENT ONLY PASSES
MAJORITY OF GLOBULIN MOLECULE HAVING LOST ALTERED PART
MAJORITY OF GLOBULIN MOLECULE ONLY REQUIRING ALTERED PART
IMMUNE
ALTERED COMPONENT CIRCULATING
ALTERED COMPONENT EXCHANGED FOR NORMAL
MATERNAL CIRCULATION
PLACENTAL BARRIER
FOETAL CIRCULATION

FIGURE 3 – *These diagrams illustrate the various methods of transfer of normal and immune globulins suggested in the text.*

It has been shown repeatedly that relatively small quantities of blood are necessary to immunize both humans and rabbits, and Levine has suggested that foetal red cells escape from the placenta in pregnancy in sufficient numbers to stimulate antibody production if they contain incompatible Rh antigens. He was able to immunize rabbits with fourteen minute daily injections of blood, equivalent to 0·0672 c.c. of blood cells for a 120 lb woman.

It is difficult to accept this theory for every pregnancy, since haemolytic disease is relatively rare. To explain this, Haldane put forward the possibility that permeability of the placenta is controlled by an extra gene, but there are no facts to support his contention.

It is possible that sufficient foetal Rh antigen, contained either in whole erythrocytes or in the products of cell disintegration, does enter the maternal circulation to enhance antibodies already present. One of us has suggested that this is the case, but that the whole process has to be initiated by sudden exposure to a large dose of the antigen in question—either by transfusion, whole blood injections, rupture of placental vessels, or massive infarction of the placenta.

It appears unlikely for a woman to have obtained her initial immunizing dose while she was a foetus herself, although this could be considered a theoretical possibility in those cases where the position is reversed, and there is an Rh positive mother of an Rh negative female foetus. Such experiments as we have done have tended to disprove this idea.

Haemolytic disease of the newborn had been observed for a long time in domestic animals, but the first serological proof of the cause being iso-immunization of pregnancy was produced by Caroli and Bessis (1947). These authors demonstrated the condition in mules. At the same time, Coombs [10] and his colleagues at Cambridge (1948) were investigating iso-immunization among racehorses at Newmarket. In the same year, confirmation of haemolytic disease came from Bruner *et al.* in America, where they also described the same disease in piglets. Haemolytic disease has also been described in dogs by Eyquem, Young *et al.*, and Abelson.

In all these animals the disease arises after suckling, and it appears that the damaging antibody is obtained by the infant through the colostrum.

In mating experiments, using Nachtsheim's strain, Coombs [10] and his colleagues [11] tried unsuccessfully to reproduce haemolytic disease in rabbits. These Cambridge workers therefore attempted to induce experimental iso-immunization in rabbits. They were successful in creating antibodies in does by injecting them with the blood of the bucks to which they had been mated. Moreover it was possible to demonstrate that maternal antibodies had crossed to the foetus, because the blood cells of the baby rabbits had antibody attached. It was remarkable, however, that although the baby rabbits received the antibodies which were attached to the cells, no clinical or haematological effects could be observed, and the baby rabbits remained healthy. However, these authors are not sure whether the antibody passed to the baby *via* the placenta, or the colostrum, or both. Similar experiments in guinea-pigs were unsuccessful.

The study of haemolytic disease in animals other than man leads us to conclude that with horses and mules the dam can become immunized to a foetal antigen inherited from the sire, but that no disease occurs in the foal during pregnancy. It is not until the foal has access to colostrum that it becomes a victim of the maternal antibody. On the other hand, it appears unlikely that haemolytic disease can be caused in rodents at all. Firstly, immunization of the female has not been shown to occur naturally, and secondly, even when artificially induced, it does not cause disease in the litter, although the antibody can be shown to reach the infant.

As yet, the nature of Rh substances is unknown, and although Rh haptens, the specific parts of the antigens, are said to have been isolated in America in lipid fractions of blood-cell extracts, it has been impossible in these and other laboratories to corroborate the findings.

Blood cells are not the only ones to contain this Rh antigen, for Boorman and Dodd (1943) were able to demonstrate its presence in many other organs by an inhibition technique. The presence of Rh antigen in brain tissues was demonstrated by Dereymaeker (1949), in placental tissues by Von Bolhuis (1948), and in solution in amniotic fluids by Witebsky and Mohn (1945).

Placental transmission has often been used as synonymous with transmission from mother to foetus; this unfortunately is not necessarily true. In the case of the rabbit, the work of Brambell *et al.* [12–14] has shown that in fact the transmission is by way of the yolk-sac splanchnopleur (one of the foetal membranes), and that the placenta is impassable to the agglutinins (*Br. Abortus*) used.

It shows also that the lumen of the non-gravid uterus may contain antibodies; that antibodies can pass from the uterine lumen to the embryo; and that for this to occur, the integrity of the yolk-sac circulation is essential. The antibody titres obtained were not correlated with the maternal titre, and these authors consider that the total amount passed may be limited by factors other than the strength of circulating maternal antibody.

They have recently demonstrated that the yolk-sac splanchnopleur of the 24-day rabbit embryo will pass antibodies prepared in the rabbit, but will only to a very limited extent pass antibodies prepared in cattle or horses. This selectivity is developed from the 20th to 24th day, and the time of development of this property is well defined. They have further shown that the selectivity is independent of molecular size. This they did by using rabbit agglutinins and haemolysins, and bovine and equine agglutinins and antitoxins. The rabbit bacterioagglutinins have relatively small molecular size, while those of cattle and horses are large. The haemolysins of rabbits immunized against sheep red cells, however, belong to the group of antibodies of large particle size. The rabbit antibodies were always admitted, whereas the equine and bovine antibodies of similar molecular size were partially held back or totally excluded. Where the yolk-sac splanchnopleur was exposed to a mixture of sera, there was no evidence of interference, and the selection did not appear to be influenced by the total mass of the molecules.

The theoretical views put forward at the conclusion of their paper suggest that the selectivity of the foetal splanchnopleur is due to cellular phenomena. They postulate that foreign antibodies are either fixed or excluded by the membranes, whereas homologous antibodies pass into the membrane and are subsequently released.

When we are considering the passage of antibody from mother to child, we find that some types of antibody are transmitted well, and others poorly if at all. Different sorts of Rh antibodies are recognized according to whether or not they clump appropriate red cells in saline. The types of Rh antibody which do not clump cells in saline may do so in protein media, and all can be demonstrated by their property of 'sensitizing' erythrocytes. The method used for the detection of 'sensitized' cells is that devised by Coombs [15]. These antibodies are reported to have different properties with regard to transmission from mother to child. Thus the 'incomplete' or sensitizing antibodies reach the infant's circulation, while the simple 'saline-acting' agglutinins do not. This is an interesting observation in view of the findings of Timmerman already described, where typhoid H agglutinins pass readily but O do not.

We consider it is a tempting hypothesis that the mechanism by which antibodies reach the foetal circulation may involve the breakdown of the complex molecule of antibody into its constituent parts, and that these pass across the placenta to be re-formed into antibody on the foetal side. This might require the existence of a specific group or arrangement of groups for each antibody which would pass unchanged through the placental epithelium. Conceivably such groups might be only minute fractions of the complete antibody globulins. The hypothesis put forward by Brambell requires the passage into the cells of large protein molecules, but does not explain how this comes about. It may be that the penetration of the cell is in itself accompanied by degradation and resynthesis before the homologous antibodies are released. This would, of course, explain the selectivity observed, since the recombination of proteins foreign to the species would be unlikely. On the other hand, the small specific groups which we have suggested would have much less difficulty in passing into such a cellular barrier than whole globulins.

To satisfy our hypothesis, there are two principal ways in which the immune globulin could be manufactured for the foetal circulation:

1. The maternal antibody may arrive at the placental barrier in its constituent parts or may be broken down by the cells, to be resynthesized either at the foetal surface or at a distance.
2. The specific grouping alone may pass across, and be resynthesized either at the foetal surface, or at a distance, with the remainder of the globulin derived from the foetus. These are illustrated diagrammatically in figures 2 and 3.

The difference between the alternatives is that, in the first case, the antibody is reconstituted from materials entirely derived from the maternal side, whereas, in the second, the foetal tissues must synthesize the majority of the globulin molecules, requiring only the special grouping from the maternal circulation.

Mechanisms of this type render it easier to understand the fact that we and others have demonstrated higher levels of antitoxin in the foetus than the mother. Also they would allow for the high values of gamma globulin found in cord bloods by Longsworth *et al.* (1945) [16]. It may be significant that it was the gamma fraction only which these authors found so high.

We have not discussed the method by which antigenic material reaches the mother from the foetus in iso-immunization of pregnancy. On a hypothesis analogous to that which assumes antibodies to reach the child by a process of disintegration and resynthesis, Coombs has suggested that antigens may be degraded and recoupled to maternal protein in certain individuals after passing the placenta, and so become antigenic once more.

The clue to an alternative route for the passage of immunity to the foetus may lie in the observation that amniotic fluid contains appreciable quantities of antibodies. Since it is accepted that this fluid passes through the mouth into the gut, it is possible that the foetus may obtain immunity in this way during intra-uterine life; the experiments of Potter and others have demonstrated the absorption of amniotic fluid through the lungs and gut as early as the twelfth week of pregnancy. This method would, of course, be analogous to the absorption of antibodies from colostrum in sheep, horses, and other animals after birth.

To sum up, it appears to us uncertain to what extent placental transmission is used in the transfer of antibodies to the foetus. The evidence suggests that in any one species the various methods—by placenta, by foetal membranes, by colostrum, and perhaps by amniotic fluid—may each play a part, and only the amount which each route contributes may vary with the species. Whichever method is used, it appears to us likely that the whole antibody does not pass over unchanged, but that it may only be necessary for a small specific fraction of the gamma globulin to reach the foetal circulation, and that the antibody is completed on the foetal side.

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Sex in the honey-bee

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About 100 years ago the great bee-master Johann Dzierzon (1845) first advanced some convincing experimental evidence that drones of the honey-bee arise from unfertilized eggs; he thus started a lively controversy which lasted for over fifty years. That parthenogenesis or virgin birth occurs in the bee is accepted today as an undisputed fact, and drones are considered to be haploid individuals. Relation between sex and size is still obscure.

Cytological investigation of the honey-bee, begun by von Siebold (1854) and continued by Blochman (1889), Petrunkewitsch (1901), Meves (1907), Nachtsheim (1913), and others, has established that the unfertilized egg which develops into a drone possesses only half the number of chromosomes of the fertilized egg. On the maturation of the sperms, the usual halving of chromosome number does not take place, since the cells already contain the reduced or haploid number. The females—queens and workers—arise from fertilized eggs and contain the diploid number of chromosomes, i.e. a haploid set derived from the egg nucleus and a haploid set from the fertilizing sperm nucleus. The diploid eggs developed within the female undergo a reduction from diploid to haploid immediately after they are laid. If unfertilized, they contain the haploid number and develop into drones; if fertilized by a haploid sperm they contain the diploid number and develop into females.

In certain Hymenoptera, e.g. some saw-flies and gall-flies, males are unknown or exceedingly rare, and the eggs, being of necessity unfertilized, yield not males, as in the bee, but females. This type of parthenogenesis is known as thelytoky, and diploidy is maintained from generation to generation either by non-reduction during maturation (*Thrinax macula* [18]) or by temporary reduction followed by a restoration of the diploid number (*Pristiphora pallipes* [4]). (See page 34.)

LAYING WORKERS

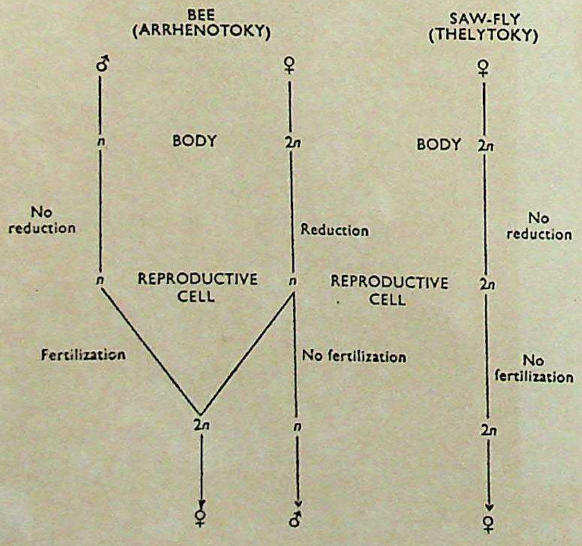
In the bees, wasps, and ants, however, parthenogenesis is apparently almost exclusively of the arrhenotokous type, that is male-producing, but from time to time bee-keepers report that worker bees, presumably virgin, give rise to female offspring. The worker larva normally has about 30 egg-tubes per ovary (a queen has about 200; see figure 1*d*), but they begin to degenerate before pupal life, and in the adult only from 2 to 12 tubes are recognizable (figure 1*a*), so that the normal worker is a female with degenerate ovaries. The spermatheca is rudimentary, and is incapable of receiving or storing sperm even if the genitalia would allow of insemination. Workers can produce eggs under special conditions, but such laying workers occur very rarely in well-managed apiaries. If for any reason the queen fails to lay, or is producing only drones, or if the colony becomes queenless and remains so for a time, the ovary in some of the workers may regenerate (figures 1*b* and 1*c*). Our recent examination of an imperfect hive revealed that about 80 per cent. of the workers had well-developed ovaries, some with mature eggs; the spermatheca in a few cases was enlarged, but was never as large as in a queen. Sperms are never found in smears of the contents of the spermathecae of workers, and thus the laying worker of the honey-bee cannot lay fertilized eggs. Hence it is generally believed that any eggs of a laying worker which develop can produce only drone offspring. Nevertheless, in a South African race, *Apis mellifica unicolor* var. *intermissa*, it has been reported by Onions and confirmed by Jack [11] that worker eggs develop into queens as readily as fertilized eggs of mated queens. Parthenogenetic development of females among Syrian and Tunisian bees also takes place, and has been reported among Italian bees [12].

CHROMOSOMES AND GENES

Recent work on the cytology of the honey-bee [20] has confirmed that in the drone there are 16 chromosomes in all stages of the developing sperm—in spermatogonia, spermatocytes, and spermatids. In the queen, there are 32 chromosomes in the oogonia and 16 in the reduced oocyte and polar nuclei (figures 2*b* and 2*c*). The smear or squash technique is invaluable in determining chromosome numbers. Aceto-orceïn preparations show the chromosomes somewhat distended, but cell boundaries are clear-cut, and spindle fibres—

or at least the outline of spindles—can readily be distinguished. Thus fairly accurate counts within individual cells can be made if nuclei are actively dividing. These chromosomes are not associated in pairs, as erroneously reported by previous workers [15], and, although small, they yet show a certain amount of individuality. One hooked chromosome (figure 2*a*, *h*) in male haploid cells appears to be present in duplicate in female diploid cells.

Since the publication of these results, Manning [13] has claimed to have found what he considers to be a sex chromosome in the honey-bee. This sex chromosome he identifies with the hooked chromosome previously figured by the authors [20]. According to Manning, this chromosome, after dividing to give two chromatids, is lost during the abortive first maturation division, thus leaving only 15 chromosomes in the spermatid. We have not been able to confirm this, although the occasional separation of single chromosomes from the main plate has been observed. In the female, Manning finds only 31 in the oogonia; he considers the unpaired chromosome to be a sex chromosome (15 pairs + X). He states that, during maturation of the egg, the odd unpaired chromosome is probably retained in the female pronucleus, and that the fertilized female-producing egg will therefore contain 31 chromosomes —15 from the male pronucleus and 16 from the female pronucleus. However, photographs and figures submitted in support of his theory of differential maturation are unsatisfactory. Nor does he give any illustration of oogonial plates showing the unpaired so-called sex chromosome.



It may, of course, yet be proved that sex chromosomes do exist in Hymenoptera.

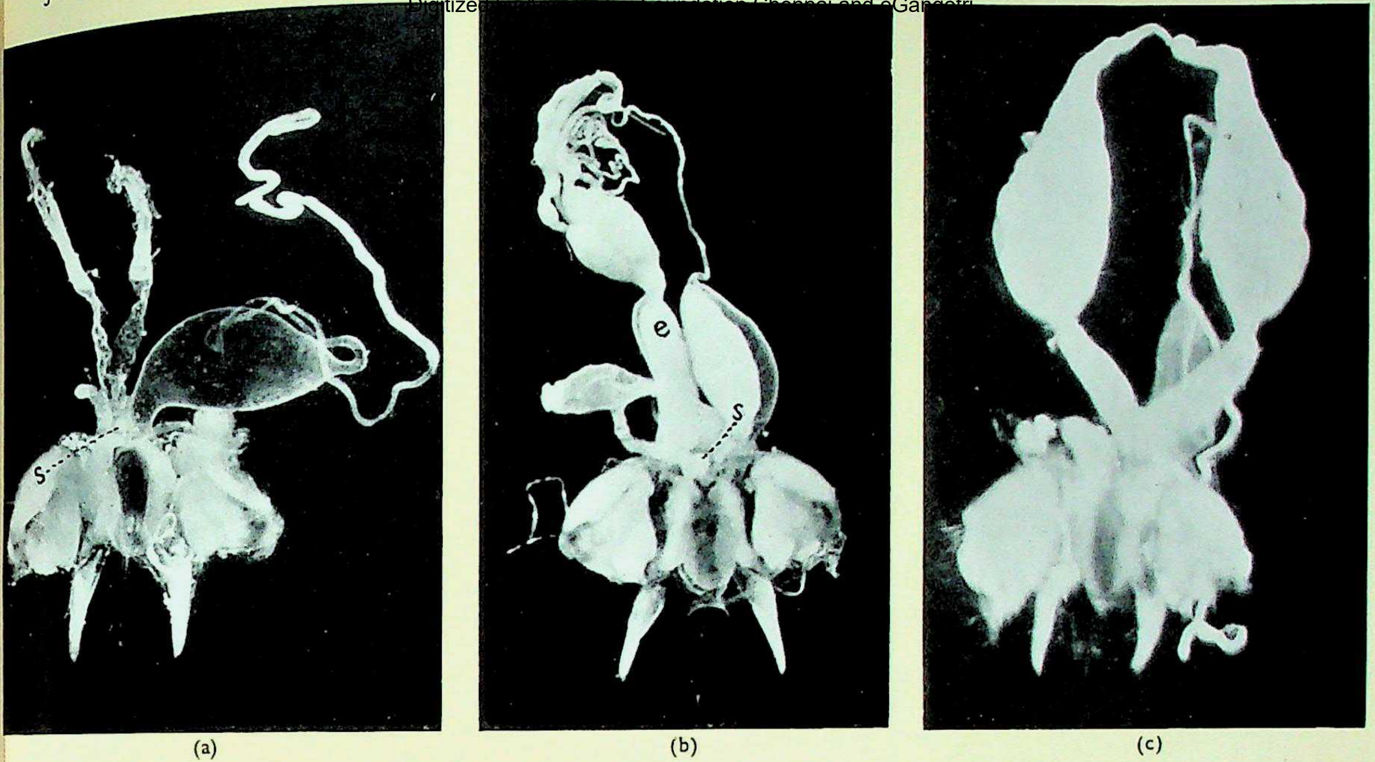
From genetical experiments, Whiting [22] postulates the existence of sex-determining genes in the ichneumon-fly, *Habrobracon juglandis*. They form a series of multiple alleles having similar effects phenotypically, and the approximate location of these sex-differentiating segments has been determined cytologically. The female-determining genes are dominant, and in the heterozygous diploid condition a female results; in the azygous or hemizygous haploid and recessive condition a male results. In the homozygous, double recessive, condition diploid males can be produced, but these are usually inviable. Sex determination is therefore regarded as complementary, and not dependent on genic balance as in non-parthenogenetic types such as the fruit-fly *Drosophila*.

BIPARENTAL MALES

The occurrence of uniparental females in the honey-bee, namely in the South African race, is exceptional, but even more remarkable is the discovery of biparental and diploid males of *Habrobracon* [23,10], a phenomenon unique among Hymenoptera. That they are biparental is shown by the fact that they carry both maternal and paternal characters. That biparental drones occur in the honey-bee is sometimes maintained by bee-keepers, but rigid proof is lacking. In the honey-bee, the mating of the queen is not readily controllable, since copulation takes place in the open, but successful artificial insemination can now be effected [3]. This obviates any doubt as to the paternal origin of characters transmitted to the offspring. Since sperms may remain viable within the spermatheca of the queen for two years, and may even survive after removal and re-injection into a second queen, it should now be possible to obtain closer matings and genetic combinations—for example, father-daughter as well as mother-son matings. By this method, close inbreeding would be ensured, and thus biparental males might be obtained experimentally.

HAPLOIDY AND THE SOMATIC CHROMOSOME NUMBER

Cytological examination reveals that the germ cells in these biparental males of *Habrobracon* are diploid. Their genetical character does not concern us here, but their very existence has led to further investigation of the haplo-diplo relationship of males and females—not only in this particular braconid, but in Hymenoptera in general. Thus,



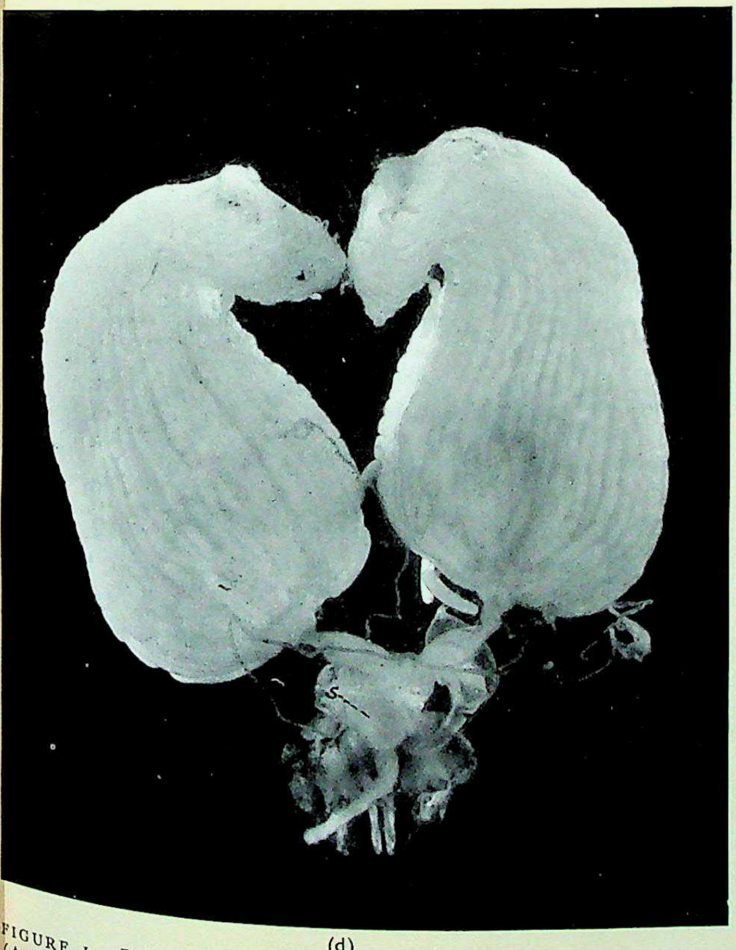


FIGURE 1 – *Dissection of ovaries and genitalia of queen and worker bees* (Apis mellifica *L.*). (a) *Normal worker, showing rudimentary spermatheca* **s**. (b) *Laying worker, showing ripe egg* **e** *in oviduct and slightly enlarged spermatheca* **s**. *Left ovary cut away.* (c) *Laying worker, showing both ovaries very well developed.* (d) *Normal laying queen, showing very large spermatheca* **s**. ((a), (b), *and* (c) × 3, (d) × 7)

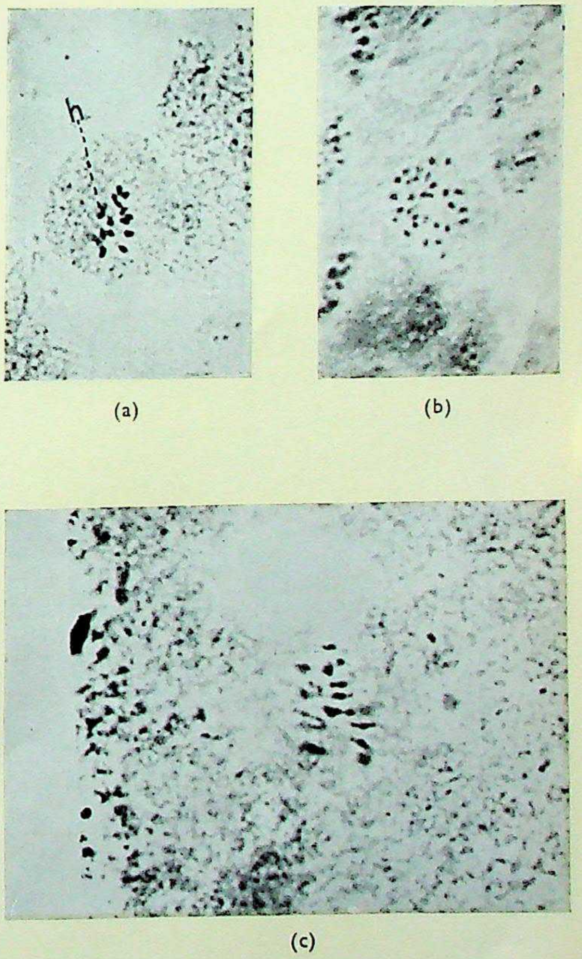
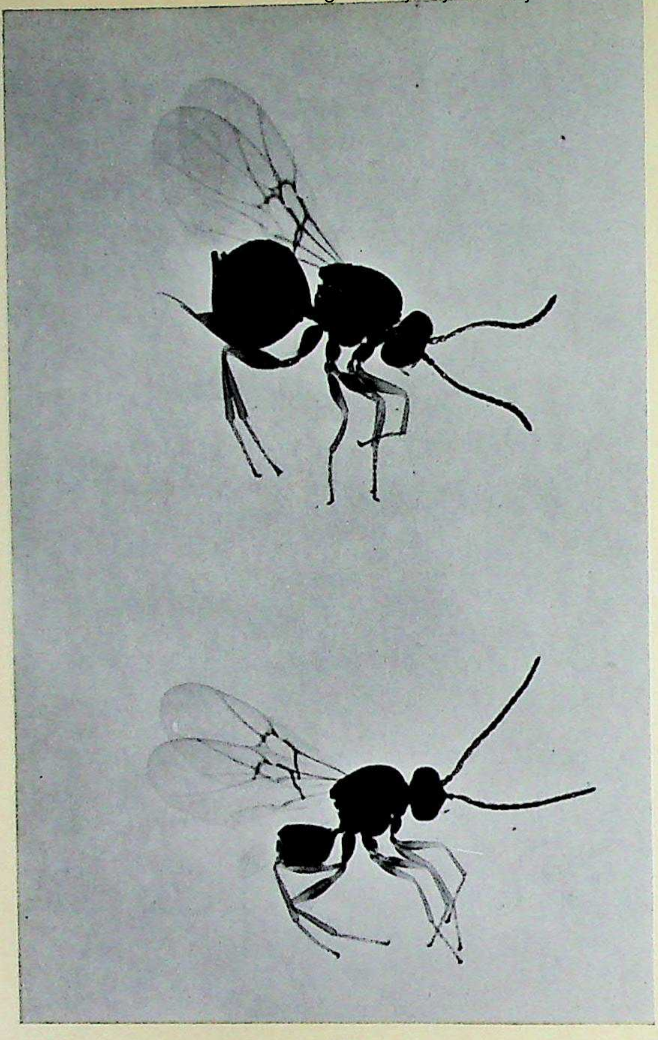
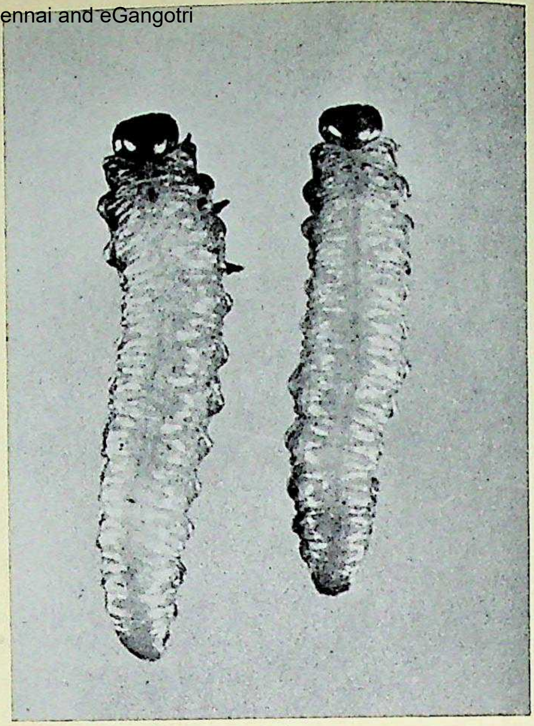


FIGURE 2 – *Photographs of chromosome plates of* Apis mellifica *L., stained with aceto-orcein.* (a) *Spermatogonial cell with* 16 *chromosomes, showing hooked chromosome* **h**. (b) *Oogonial cell with* 32 *chromosomes.* (c) *Egg maturation, first spindle, showing* 16 *bivalents.* (× 1800)



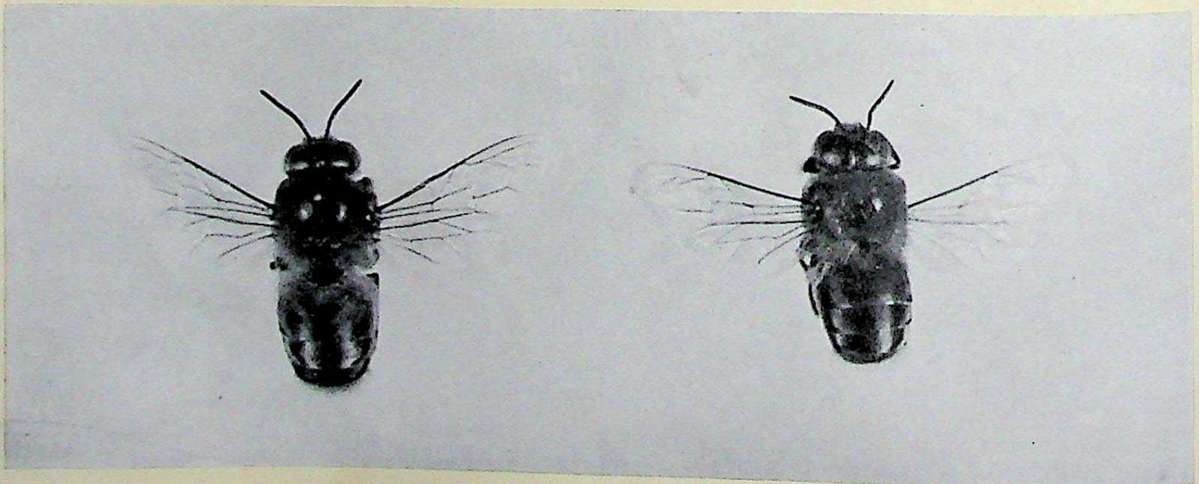
(a)



(b)

FIGURE 3 – *Photographs showing difference in size in male and female gall-flies and saw-flies.* (a) *Adults of cynipid* Andricus curvator *Htg.—male* below, *female* above (× 10). (b) *Larvae (prepupae)* (♀ *left*, ♂ *right*) *of gooseberry saw-fly*, Pteronidea ribesii *Scop., photographed at moult before spinning cocoon, and subsequently dissected in order to verify sex* (× 6).

FIGURE 4 (*below*) – Apis mellifica *L. Drones from laying worker, from worker comb.* (× 2·5)



(*Photographs* 3(b), 4, *and* 5 *by F. L. Waterhouse, M.Sc.*)

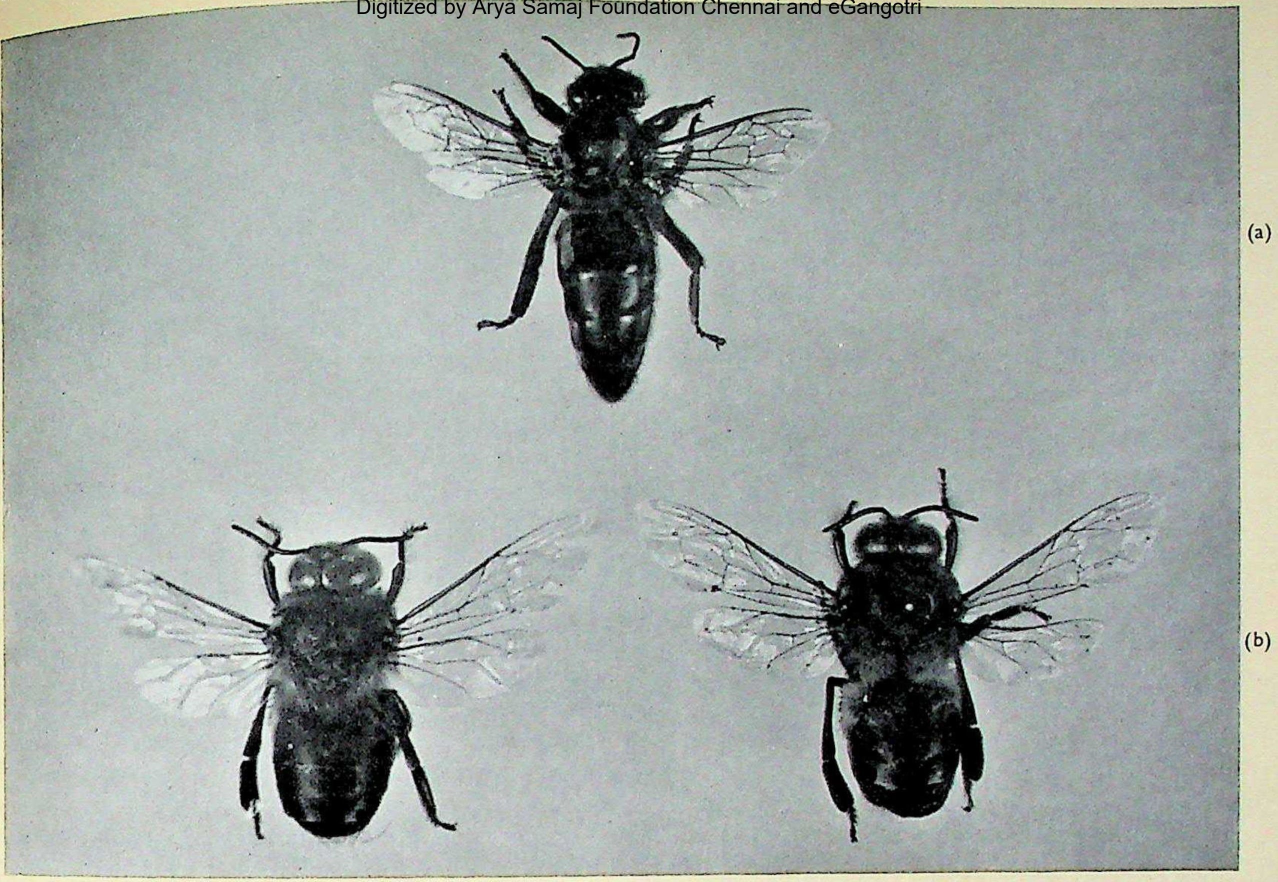


FIGURE 5 – Apis mellifica *L.* (a) *Fertile laying queen.* (b) *Normal drones from drone comb.* (× 2·5)

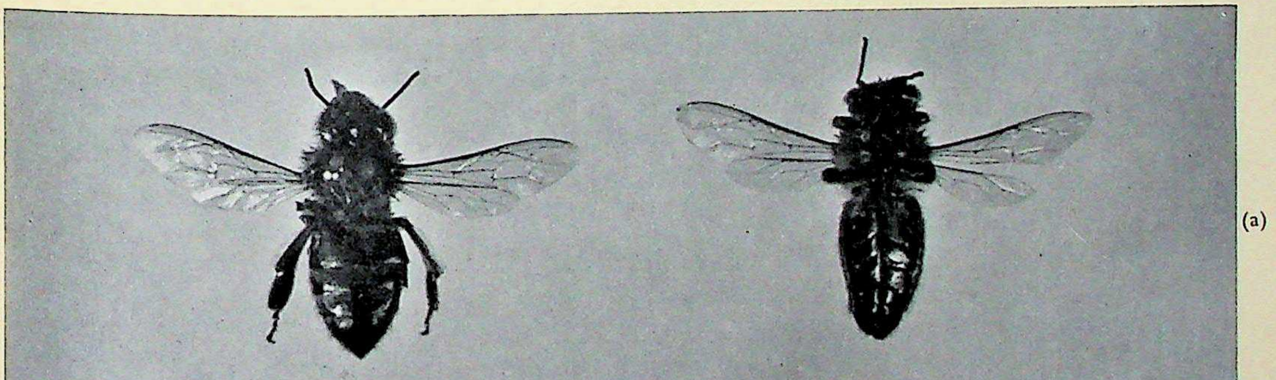


FIGURE 6 – Apis mellifica *L.* (a) *Laying workers, showing dorsal aspect* (left) *and ventral aspect. Note that the abdomen is larger and more keeled than in the normal worker.* (b) *Normal worker in dorsal* (left) *and ventral aspect.* (× 2·5)

today, interest tends to be focused not so much on the maturation of the gametes as upon the chromosome constitution of male and female tissues, both germinal and somatic.

In smear and squash preparations of developing hymenopterous gonads, one can readily obtain chromosome plates with the unreduced or diploid number in the female, and reduced or haploid number in the male (figures 2*a* and 2*b*). Somatic tissues are not so easily investigated. Numerous mitotic divisions yield good counts, but one frequently finds that these plates are polyploid, containing not the expected haploid or diploid sets of chromosomes (genomes) but sometimes three, or, more often, four or eight genomes. Unfortunately, irregularities in chromosome number among somatic cells in both animals and plants are much more common than is generally supposed, and not only in the direction of polyploidy. Berger [1] found that somatic segregation is a regular occurrence in the gut of mosquito larvae, and, more recently, Huskins [9] and his colleagues have found segregation or reduction to the haploid condition (or both) in root tips of the onion.

The haplo-diplo relationship in the bee can be demonstrated readily in the reproductive cells, but not so readily in the somatic cells. Thus, while a developing drone bee has 16 chromosomes in the spermatogonia and spermatocytes, there may be 32 in the follicle epithelial cells of the testis, and 16, 32, 64, or more in developing hypodermal or tracheal cells. Similarly, a developing queen may have 32 in the oogonia and 32, 64, 128, etc., in the ovarian follicle cells or imaginal tissues. If we consider the gonial count as the basic somatic number, the drone is a haploid individual and the female a diploid.

In view of statements such as that of Whiting [22] that 'the diploid drone (of the honey-bee) breeds as a haploid although he produces diploid sperms,' it seems that the time has come for a better definition of what is meant by the terms haploid and diploid organisms. In this article the terms haploid and diploid have been used to describe the condition existing in the primary reproductive cells—haploid where only one genome is present (♂), and diploid where two genomes are present (♀).

HAPLOIDY AND BODY SIZE

It is an obvious fact that, in the non-social Hymenoptera, males are on an average much smaller than females—for example in gall-flies and saw-flies (figures 3*a* and 3*b*). We do not know whether the smaller size of the male individual is due to its having relatively smaller tissue cells than the female, or whether it has a smaller number of normal-sized cells. Comparisons of cell size in arrhenotokous types have been made by Oehninger [16] and Whiting [22]. The latter finds that in the haploid male of *Habrobracon* the cells are almost as large as in the female, while diploid males have larger cells than diploid females. Cell size therefore appears to increase with the number of genomes, but it would seem that maleness itself is an even more effective factor.

In the social insects such as bees, wasps, and ants, the sexual forms do not show any great disparity in size, owing to special feeding during larval life (figures 5*a* and 5*b*). If drones are developed in worker comb, as in the case of offspring of laying workers, they are recognizably smaller than drones from the larger drone cells (figures 4 and 5*b*), thus indicating a quantitative influence by the food. With regard to polymorphism in the honey-bee females, it would appear that nourishment again plays an important part. As already stated, the ovary in the younger worker larva normally has about 30 egg-tubes, but before pupation it has begun to degenerate. If, later, a worker should regenerate the ovaries, so that eggs are produced, the abdomen will appear to be somewhat larger than that of a normal worker (figures 6*a* and 6*b*). Haÿdak [8], discussing larval food and development of castes, concludes that morphological differences displayed by queen and worker are due to quantitative differences in the food. Queens are given bulk feeding during the whole of their larval life; workers during the first three days only, feeding thereafter being direct from the nurse bees. The size of the worker bee is therefore no criterion for comparison with that of the male, as the worker is a very specialized sterile female. In certain ants, the differences in size between the fertile and sterile castes are even more marked, the workers being extremely small. In the ant *Monomorium pharaonis* L., differences in the fertile and sterile females appear to be due to quantitative differences in feeding (Hall and Smith, unpublished). The haploid male is not much smaller than the diploid queen [17], but one cannot ignore the possibility of the effects of special feeding.

In establishing the haplo-diplo relationship of the soma in the male and female of the honey-bee, where polyploidy is so prevalent, it will be necessary to ascertain that the cells examined for chromosome counts are of comparable generations.

This might be ensured by counting the number of cells in one particular structure—for example, a nerve ganglion, where polyploidy is not so prevalent. Cell sizes could then be compared, and chromosome counts of mitotic cells of the same generation might be obtained in the two sexes.

A new method of investigation has been suggested by recent biochemical researches [5]. In a number of vertebrates which have been examined there is in all somatic cells of the body a measurable amount of a certain nuclear constituent, viz. desoxyribonucleic acid (D.N.A.), and this is constant for any one type. As is to be expected, the D.N.A. value for sperm nuclei is half that of the normal somatic nuclei, since the sperm contains only half the amount of chromatin present in the somatic cell. Having ascertained the D.N.A. constant for any particular species, and the amount per unit of tissue weight, the number of cells present in any sample can be determined. If this method can be successfully applied to insect tissues it may be possible, by a comparison of male and female tissues in parthenogenetic species, to determine whether differences of body size are due to differences in number of cells. The advantage of applying this method would be that the total number of cells could be calculated for the entire insect. It has been shown by Sanderson [19], Miles [14], and Smith [21] that in certain saw-flies which produce males by haploid parthenogenesis, the male larvae in any mixed brood are recognizable by their smaller size. Although cytological observations on saw-flies [19] have suggested that male haploid cells are smaller than comparable female cells, with this new technique it may now be possible to reinvestigate the problem. Although polyploidy most certainly occurs in many tissues, its extent is apparently comparable in both sexes. Thus any inaccuracy in the calculated nucleic acid value per nucleus, due to the presence of a percentage of polyploid cells, would be negligible when comparing the two sexes.

So far we have not considered egg size in dealing with progeny of laying workers and queens. Flanders [6] believes that oosorption takes place when ovulation of the egg is delayed, and that the subsequent loss of nutriment (or egg degeneration) is the basis of polymorphism in certain social Hymenoptera. Although no data are available on the influence of egg volume on the size of resulting embryos in the honey-bee, work of such a nature carried out on frog embryos [2] shows that increased rate of growth gradually compensates for initial smallness.

Thus differences in body size in Hymenoptera may be due to one or all of the following causes: (1) feeding; (2) size and number of tissue cells, correlated with the chromosome complement; (3) initial size of egg.

CONCLUSION

In the authors' opinion male Hymenoptera are to be considered haploid organisms, first because the gonad is definitely haploid in constitution, and secondly because early cleavage and embryonic cells are haploid. The uniparental haploid male is generally markedly smaller than the biparental diploid female. In *Apis mellifica* L. the queen and queen-produced drone appear to owe their increased size to special nourishment, whereas the normal worker is undersized. The drone, whether produced by a queen or a worker, is a haploid individual, and, although the true haplo-diplo size-relationship of male and female is masked by special feeding, the worker-produced drone probably gives a better indication of the natural size of the male.

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The nature of ion exchangers

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The importance of ion exchangers has increased enormously during the last fifteen years as a result of the development of synthetic materials differing from natural ones in the consistency of their properties, in their very much larger capacity, and in their ability to function under a much wider range of conditions. Apart from their large-scale applications in water-purification processes, the introduction of ion exchangers into chromatography has been of the greatest practical importance, permitting rapid separation of many mixtures of inorganic ions which have long proved intractable by the older classical methods.

It often happens that an almost forgotten phenomenon suddenly rises to the forefront of scientific and technical interest. This happened to the process of column separation by adsorption discovered in 1906 by the Polish biochemist Tswett. After a substantial period of obscurity it slowly developed—first as a means of purification, then as a method of separation—into one of the most powerful tools at the disposal of the chemist for the separation of substances which resist other attempts at isolation.

The phenomenon of ion exchange, now firmly coupled with column separation, has a still older history. Its importance for the chemistry of soils was realized by Way a century ago [1], and among the early studies of its physical basis may be mentioned the work of Rothmund and Kornfeld on the exchange properties of zeolites, a type of alumino-silicate.

It was the discovery by Holmes and Adams in 1935 of synthetic resinous ion exchangers [1], rendering possible the manufacture and, one might almost say, the design of ion exchangers of reproducible and well-defined properties, which raised the status of ion exchange to that of an important technique, the applications of which now pervade an ever-growing field of science and industry. Nowadays we cannot open a scientific or technical journal without being reminded of its almost universal applications: separation of organic bases, of amino acids, of isotopes; treatment of blood; purification of sugar; demineralizing of oils; production of pure rare earths; and preparation of conductivity water.

TYPES OF ION EXCHANGER

The resins used are generally produced by a polymerization process such as the condensation of polyhydric phenols with formaldehyde, or they may be polystyrene-like substances cross-linked by the addition of varying amounts of divinylbenzene (see figure 1). The exchanging groups may be introduced either before or after condensation.

Cation exchangers. These are resins which embody acid groups such as $—SO_3H$, $—CO_2H$, or phenolic $—OH$. While the first type behaves like a strong acid and consequently exchanges its hydrogen equally well at all *p*H values, the carboxylic resins can be used only at medium to high *p*H, because the hydrogen in the only moderately dissociated $—CO_2H$ group is difficult to replace by other ions if the surrounding solution contains excess hydrogen ions as well. This is still more so in the case of $—OH$ groups, which, like those in simple phenols, give up their hydrogen only in quite alkaline solution. However, while a sulphonate exchanger is obviously required for use in acid solutions, the carboxylic resins are not without advantages in neutral solutions, as not only is their capacity very high (up to 10·5 equivalents per kg as compared with 4·8 for the best sulphonates), but they are frequently more selective in their exchange properties.

A new type of resin which may have a great many uses is being evolved in the 'chelating' resins [2]. These are extremely selective for elements of the transition groups.

Anion exchangers. Just as resins with acid groups act as cation exchangers, those with amino groups in their structure can act as adsorbers or exchangers of anions. While the amino groups of the earlier anion exchangers were only weakly basic, and would not adsorb anions in alkaline solution, the more recently developed exchangers utilize substituted amino groups such as

$$—N(CH_3)_3^+, \ —N(CH_3)_2(CH_2C_6H_5)^+,$$

and

$$—N(CH_3)(CH_2C_6H_5)_2^+$$

which are more basic in character. The last type of resin is so strongly basic that any sodium salt solution passing through a column of it will emerge as pure sodium hydroxide solution.

Both cation and anion exchangers can be made in a variety of forms, e.g. granular and spherical, and a number of them also as rods, plates, and membranes. Their physico-chemical properties can be considerably altered by variation of the starting materials and of the degree of cross-linking of the monomer chains.

PHYSICAL CHEMISTRY OF ION EXCHANGERS

Distribution equilibria. An important feature of the ion exchanger is its ability to differentiate between the various ions, that is, to show preference of adsorption to one kind as compared with another. This property is defined by the separation factor k_s:

$$k_s = \frac{X_2 c_1}{X_1 c_2} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where X_2/X_1 is the ratio of the molar fractions of the two ions I and II in the resin phase, in equilibrium with the corresponding concentrations c_1 and c_2 in the aqueous phase. This factor need not be constant under varying conditions; it may for example depend on the total concentration of the aqueous solution, or on the ratio X_2/X_1, or on the presence of a third solute. In order that two solutes should be easily separable, k_s should differ as much as possible from unity. k_s is an important parameter in the equations derived in the theory of chromatographic column separation. The greater its difference from unity, the shorter can be the column required for the separation of a given quantity of material, the faster can be the rate of flow through the column, and the sharper will be the boundary between different zones of components. Naturally, therefore, a great deal of research [3, 4, 5] has been directed towards the determination of separation factors for different ions.

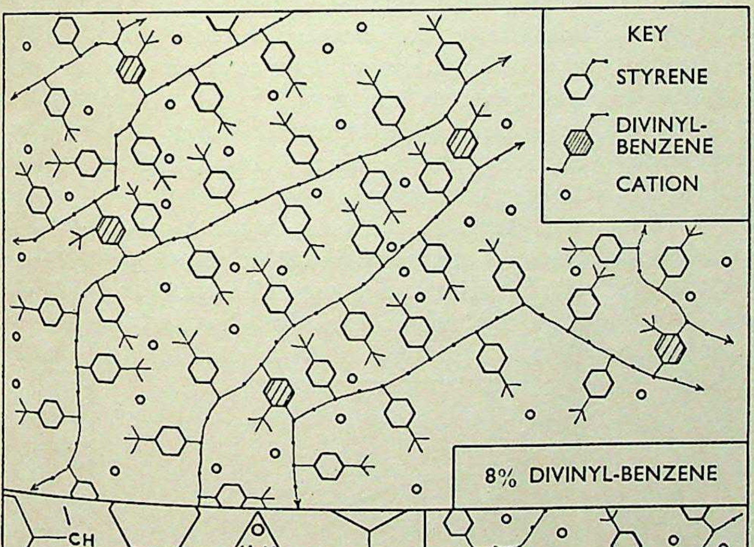

FIGURE 1 – *Schematic representation of cross-linked sulphonated styrene exchangers. Note the much more rigid cross-linking for a high divinyl-benzene content.*

Generally speaking, the affinity of the exchanger for an ion increases with the ionic charge of the latter: thus $Th^{4+} > Al^{3+} > Ca^{2+} > Na^+$. Within a given valency type, one has a considerable choice in expressing the order—the affinity goes with increasing atomic mass, or with increasing volume of the unhydrated ion, or with decreasing radius of the hydrated ion—but whatever the explanation, the order is usually: Cs > Rb > K > Na > Li, and Ba > Sr > Ca > Mg > Be, and La > Al. The group NH_4^+ behaves rather like potassium, being usually slightly more strongly adsorbed. The position of the hydrogen ion varies for different types of exchanger. For weakly acid exchangers, e.g. those containing carboxyl groups, it is the most strongly adsorbed univalent ion and is probably covalently bound; whereas for strongly acidic exchangers containing sulphonate groups its affinity falls between those of Li and Na, and is usually nearer to the former, so it is presumably contained in the resin as a hydrated ion.

The affinity for substituted ammonium ions increases with their size.

$$NH_4^+ < (NH_3CH_3)^+ < NH_2(CH_3)_2^+ < N(CH_3)_4^+ < N(C_2H_5)_4^+,$$

though a limit is reached owing to

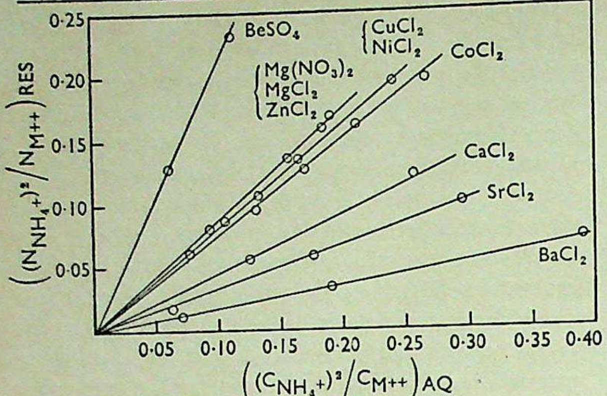

FIGURE 2 – *Test of equation* 3 *for the exchange of heterovalent ions.* (*After Kitchener and Kressman* [5].)

the inability of very large cations such as

$$N(C_2H_5)_2(CH_2C_6H_5)_2{}^+$$

to diffuse into some of the resins.

No simple rule applies to the ions of the transition elements. The univalent ions Tl^+ and Ag^+ are more strongly adsorbed than other ions of the same valency, but the affinity of Cu, Ni, and Co, for example, lies between Mg and Ca (see figure 2).

When ions of different valency exchange, it depends to a large extent on the total concentration whether the separation factor k_s is larger or smaller than unity, i.e. which of the ions is the more strongly adsorbed. Let us take a case where the ions I and II are of the valencies v_1 and v_2 ($v_1 > v_2$), the aqueous concentrations are c_1 and c_2, and in the resin phase the equivalent fractions are x_1 and $x_2 = 1 - x_1$. Then the stoichiometric reaction of the exchange is (neglecting the movement of water during exchange):

$$v_2[\mathrm{I}]_{sol} + v_1[\mathrm{II}]_{res} \rightleftharpoons v_2[\mathrm{I}]_{res} + v_1[\mathrm{II}]_{sol} \quad ..(2)$$

which results at equilibrium in a mass-law equation

$$\left[\frac{c_1}{x_1}\right]^{v_2}\cdot\left[\frac{x_2}{c_2}\right]^{v_1} = k_e \; ....(3)$$

The equilibrium factor k_e should not be confused with the separation factor k_s.

$$k_s = \frac{X_2 c_1}{X_1 c_2} = \frac{v_1}{v_2}(k_e)^{1/v_2}\left(\frac{c_2}{x_2}\right)^{(v_1-v_2)/v_2} \; ....(4)$$

Thus, while the ion with the higher valency is more strongly adsorbed in dilute solution, it follows from equation 4 that, by greatly increasing the total aqueous concentration, the relative affinity of the ion of lower valency (II) is increased, and the preference as expressed by k_s is sometimes reversed altogether.

The equilibrium factor k_e would be expected to be nearly independent of the total aqueous concentration and of the ratio of the ions in the resin phase, and indeed, if $x_1^{v_2}/x_2^{v_1}$ and $c_1^{v_2}/c_2^{v_1}$ are plotted as abscissae and ordinates respectively, the curves obtained are often reasonably linear (see figure 2, from the paper by Kitchener and Kressman [5]).

That they do not always follow the linear plot accurately is due to a number of simplifying assumptions which are contained in equation 3. Strictly, one should have used, not concentrations and equivalent fractions of the ions, but the electrolyte activities in the solution and in the resin phase. For the aqueous phase, these can sometimes be evaluated from tables, but, up to now, we know almost nothing of the activities in the resin phase, and the estimation of their values depends largely on the assumptions made by different authors. Moreover, in equations 2 and 3 the movement of water in and out of the resin phase, due to the different hydration of different ions, has been neglected. To consider it would lead to another term in equation 3 containing the water activities, and the change also affects the activities of the ions in the resin phase. At high aqueous concentrations, yet another factor comes into play, as the resin takes up electrolytes in addition to the exchangeable ions, thereby greatly affecting the internal 'concentration' and the activity coefficients.

In high-capacity resins these deviations from the ideal can be very marked, especially when ions of the transition group elements are concerned. Figure 3 shows variations of k_e (which, if the

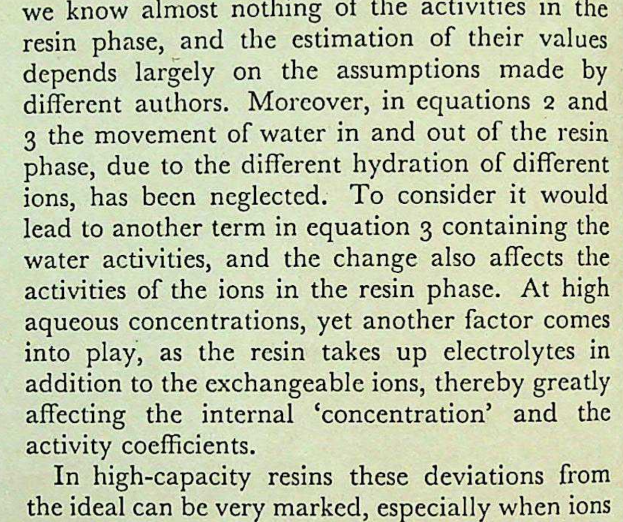

FIGURE 3 – *Variation of the equilibrium 'constant'* k_e *for the exchange of silver against sodium on Dowex* 50 *with the fraction of silver on the exchanger* [7]. $k_e = x_{Ag}a_{Na}/x_{Na}a_{Ag}$.

equivalent fractions did represent the activities, should be almost constant) with composition of the resin, for the exchange of Na and Ag on Dowex 50 (a commercial product). As the equilibria of figure 3 were determined in dilute solutions, and as, moreover, the activity coefficients in the aqueous phase were taken into account, the cause of this deviation from the ideal must be sought in the resin phase; the only phenomena which can explain this big variation of k_e must involve a fairly energetic interaction between the two adsorbed cations. This interaction may be due either to a dehydration of one ion by the other, or to mutual electrostatic repulsion of the ions, which in the circumstances may vary the degree of formation of ion-pairs with the sulphonate group of the resin. Increased ion-pair formation by one of the exchanging cations would lower the activity of this cation in the resin phase, and thereby result in its being more strongly adsorbed.

SWELLING AND ELECTROLYTE-UPTAKE OF RESINS

Experiments in this field are concerned with the following factors:

1. The loss of water by resins with different cations under reduced water-vapour pressure [2]. (See figure 4.)
2. The loss of water, and
3. the uptake of excess electrolyte by the resins when in contact with concentrated aqueous solutions containing salts of the exchanging cation [2].
4. The conductance and the electrolytic transference in the resin [2].

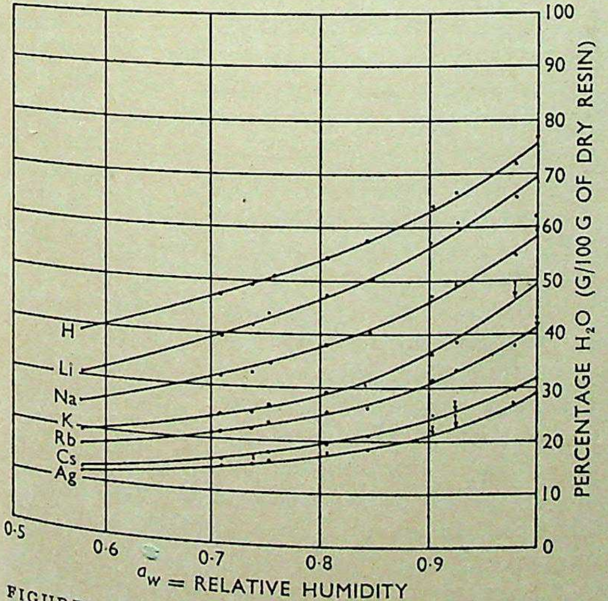

FIGURE 4 – *The swelling-water content of Dowex 50 with different cations under varying water-vapour pressure* [7]. $a_w = p_{H_2O}/p_{H_2O\ saturated}$.

Some results are shown in figure 5. They show clearly the considerable volume change which the resin undergoes when placed in solutions of various concentrations. It is apparent that a physico-chemical treatment of resin equilibria must take into account the work involved in elongating or contracting the cross-linked chains of the resin. These experimental results make it necessary to visualize the resin phase as a concentrated aqueous electrolyte solution constrained by the somewhat elastic resin structure, which prevents the resin from swelling beyond a certain limit. The application of thermodynamics [2] to such a model makes it possible to estimate roughly the amount of electrolyte-uptake observed in experiments of the type shown in figure 5. In doing so, it is found that the actual uptake considerably exceeds the theoretically estimated one, which can only mean that the electrolyte activity inside the resin is considerably smaller than it would be if the mean molal activity coefficients of the resinate had values comparable to those of other Na salts, e.g. chlorides or nitrates. The same conclusion has been reached by W. Juda from the determination of transport numbers inside the resin phase [2]. This means that an Na resinate, considered as an aqueous solution of Na ions and sulphonate ions, does not dissociate completely into two ions which can be treated as entirely independent particles in the solution. This may be so for several reasons:

1. Dissociation into anion and cation may be incomplete, possibly as a result of the presence of organic matter which would reduce the dielectric constant.
2. The anionic groups, being attached to the resin structure, may not act as completely independent particles.
3. The ionic atmospheres—as envisaged in the Debye-Hückel theory of electrolyte solutions [6]—are different from those in an aqueous solution. This may be due either to the space restrictions imposed by the organic resin matrix, or to the restricted mobility of the anions (in a cation exchanger), which does not make possible the formation of a negative ionic atmosphere around a cation.

All these possibilities act in the direction of a reduction of the mean activity and osmotic coefficients of the metal resinate, and as all of them may occur simultaneously (but to a different degree for different ions) it will not be easy to express these considerations quantitatively.

There are, however, a number of features which show that the concept of treating ion exchangers as concentrated aqueous electrolytes goes a long way towards an understanding of their fundamental properties [2].

Taking the case of the sulphonated cross-linked polystyrenes (of which Amberlite I.R.120, Dowex 50, and Zeo-Karb 225 are well-known commercial types), variations in the cross-linking of the monomer polystyrene chains can be effected by varying the amount of divinylbenzene (see figure 1). The smaller the amount of cross-linking, the less are the forces which oppose the tendency of the resin (a tendency common to all electrolytes) to form a real aqueous solution when in contact with water. This means that a resin of low cross-linkage in contact with dilute aqueous solutions will swell much more than a highly cross-linked one. Also, considered as an aqueous electrolyte solution, the swollen resin of low cross-linkage, though its capacity per gram of dry resin is very nearly the same, has a smaller resinate molality (= number of equivalents of exchanging groups per 1000 gm of swelling water).

SPECIFICITY OF RESINS OF DIFFERENT CROSS-LINKAGE [2]

When two electrolytes are present, and we have the comparatively simple case of both cations being univalent and the aqueous solution dilute, the theory for a somewhat idealized case leads to a value for the equilibrium factor k_e'

$$\ln k_e' = \ln \frac{\overline{m}_2}{m_2} \cdot \frac{m_1}{\overline{m}_1} = \frac{P}{RT}(V_1 - V_2) + \ln \gamma_{R_1}/\gamma_{R_2} \quad (5)$$

where γ_{R_1} and γ_{R_2} are the mean molal activity coefficients of the two pure resinates, P is a function of the resin volume equivalent to the 'swelling pressure' of the resin, V_1 and V_2 are the ionic volumes of the unhydrated cations, and the m's and $\overline{m}$'s are the molalities in the aqueous and resin phases respectively, which in the latter case are computed as if the resinate were dissolved in the swelling water. Now, the activity coefficients of unhydrated electrolytes in general are smaller, the bigger the ionic volumes of the unhydrated cations, e.g. $V_{Cs} > V_{Na}$ and $\gamma_{CsCl} < \gamma_{NaCl}$. The two terms on the right-hand side of equation 3 have therefore different signs. As it is known from experiment that k'_e increases with increasing value of $V_2 - V_1$, it is apparent that the term $\ln \gamma_{R_1}/\gamma_{R_2}$ is predominant, and the swelling-pressure term cannot be very significant from the point of view of the separation factor. Using the same model for ions of different valency (v_1 and v_2), the equilibrium factor becomes

$$k_e' = \left(\frac{\overline{m}_2}{m_2}\right)^{v_1} \cdot \left(\frac{m_1}{\overline{m}_1}\right)^{v_2} \quad \ldots\ldots\ldots (6)$$

where k_e' is a complicated function of the swelling pressure, the ion volumes, and the activity coefficients. As the trend of the series from Ba to Be shows, the predominant factor is the last. However, the molalities in the resin phase are not a convenient means of presenting the phase composition, as they require a knowledge of the water content of the resin. Their ratio can conveniently be replaced by that of the equivalent fractions, $x_1 = v_1 n_1/(v_1 n_1 + v_2 n_2)$ and $x_2 = v_2 n_2/(v_1 n_1 + v_2 n_2)$, as $(v_1 n_1 + v_2 n_2)$ is the resin capacity and thus constant. It cannot be replaced by the molar fractions $X_1 = n_1/(n_1 + n_2)$ and $X_2 = n_2/(n_1 + n_2)$ as the total number of mols/gm of resin $(n_1 + n_2)$ in a heterovalent mixture is itself a function of the ratio of the two ions in the resin. This supplies the explanation for the experiment of Duncan and Lister [4], who showed that, in the case of an NH_4—La exchange, a better constancy of k_e' is obtained using equivalent fractions than with molar fractions.

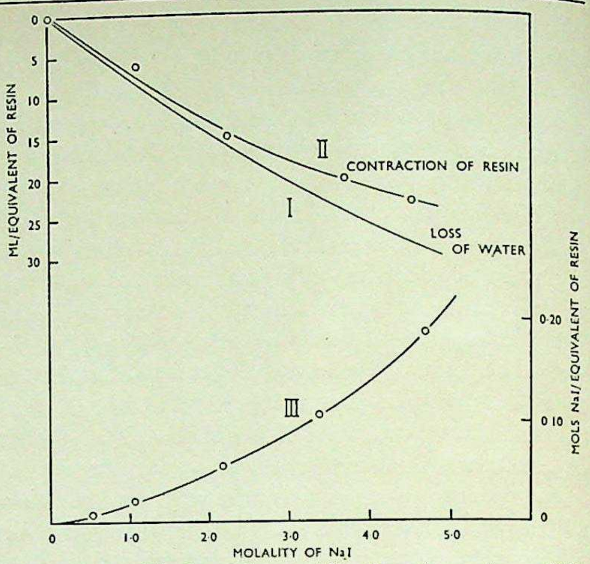

FIGURE 5 – *The loss of water (I), the volume change (II), and the uptake of NaI (III) by Na-Dowex-50, when in contact with aqueous sodium iodide solutions of different concentrations* [7].

Returning to equation 5, we noted that the equilibrium factor k_e' is mainly a function of the ratio of the activity coefficients of the two resinates. It is a well-known fact that activity coefficients of aqueous electrolytes are very similar in dilute solutions where they follow the Debye-Hückel limiting law, but that they diverge as the concentration increases. It is apparent, therefore, that as we decrease the cross-linking and thus, owing to increased swelling, turn the resinate into a more dilute 'solution,' the ratio of the activity coefficients and thus also the value of k_e' should decrease, i.e. the resin should become less effective for the separation of ions. Experiment [2] shows that this is indeed the case.

The natural consequence of this realization might be to conclude that the highest possible cross-linkage should prove most favourable for obtaining resins of high specificity. In practice, however, there is a limit to the useful increase of cross-linkage, as greatly increased cross-linking produces resins which show a very abnormal behaviour. To give an example: resins cross-linked with 20 or more per cent. of divinylbenzene, while showing a great preference, e.g. for Na^+ in an Na-H resin containing mainly H^+, show a preference for H^+ in a mixture containing mainly Na^+, with an intermediate resin composition where little or no enrichment of either ion takes place. A reason (not necessarily the only one) for this behaviour can be found if we consider that highly cross-linked resins contain very little water, and that consequently the cations in the resin do not find enough water to satisfy their normal hydration requirements. They will therefore proceed to share the available water molecules in a manner which provides the lowest possible energy level. This means that interaction will take place between different ions of the same sign—a possibility which, according to Brønsted, need not normally be considered in more dilute solutions [6]. Such an interaction would lower the mean activity in the resin of the less numerous cations more than those of the more plentiful variety, with the result that the cation species present in the minority would show a tendency to be more strongly adsorbed.

There are other considerations which make it undesirable to increase the cross-linkage of the resins beyond a certain extent. As the resins swell less, their porosity, which provides for the free and fast interchange with the ions of the solution, decreases, and the exchange velocity, which is—except in extremely dilute solutions—controlled by the diffusion of ions inside the resin phase, decreases very rapidly. Indeed, for very highly cross-linked resins, access into the interior of the resin is no longer possible for large organic ions [2].

A feature of physico-chemical interest which has so far not been specifically mentioned is the different degree of swelling of a given resin when the exchangeable cation is varied. As we change, for example, from Li to Na to Rb to Cs we find that the resin contracts owing to loss of water (see figure 4). We may explain this in various ways. We can say that each of these ions is more hydrated than the subsequently-named ones, or we may say, treating the resin as an aqueous electrolyte solution, that the osmotic coefficient of the resinates decreases in the given order, thus causing less swelling. Actually, as the osmotic coefficients of electrolytes in concentrated aqueous solutions are effectively determined by the degree of hydration of their cations, both explanations must indicate the same trend. However, the latter one gives not only a possibility for quantitative treatment, but leads also to the conclusion that cations of the same valency should be the more strongly adsorbed the less they swell the resin, and *vice versa*. Except for hydrogen, this conclusion is in agreement with the general body of experimental data.

CONCLUSIONS

It is clear that it is not possible to do more here than to touch on the various conceptions connected with the mechanism of ion exchangers, a field in which we are only just beginning to see light. Our difficulties in obtaining a complete understanding of what is going on inside the resins are increased by the fact that we are obviously dealing with what might be described as highly concentrated solutions of strong electrolytes, a subject yet little explored [6]. However, the extensive research in progress on both sides of the Atlantic shows that interest in this field is stimulated rather than discouraged by these difficulties.

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'Mr Warltire, a good chymist'

DOUGLAS McKIE

Although John Warltire gave valuable assistance to Joseph Priestley in the isolation of oxygen in 1774, and although he observed, late in 1776 or early in 1777, that a 'whitish cloud' was produced in the combustion of 'inflammable air,' practically nothing has been known of him and no biographical notice or study of his writings has hitherto appeared. Dr McKie's article is therefore a welcome addition to the biographical literature of chemistry.

John Warltire is known to historians of chemistry as an itinerant lecturer and a friend of Joseph Priestley. When, in 1774, the latter was planning the series of experiments with his new burning-glass which led to the isolation of dephlogisticated air or oxygen, he recorded that 'Mr Warltire, a good chymist, and lecturer in natural philosophy, happening to be at that time in Calne, I explained my views to him, and was furnished by him with many substances, which I could not otherwise have procured' (*Experiments and Observations*, London, 1775, ii, 34). In the course of these classic experiments, Priestley was doubtful of the genuineness of the *mercurius calcinatus* that he was using, having bought it 'at a common apothecary's', and obtained from Warltire a sample that he 'could warrant to be genuine' (*ibid.*, p. 36).

On 3rd January, 1777, Warltire wrote to Priestley to inform him of a number of observations that he had made. Among them, he reported that in the burning of a jet of inflammable air (hydrogen) in a receiver filled with common air, 'the common air is contracted full a fifth part of its original dimensions; immediately after the flame is extinguished, there appears through almost the whole of the receiver, a fine powdery substance like a whitish cloud' (*ibid.*, 1777, iii, 367).

This remarkable observation, made by Warltire late in 1776 or early in 1777, does not seem to have been noticed before by writers involved in the 'water controversy,' but it led Warltire to further and better-known experiments, which he discussed with Priestley and which were communicated to Cavendish, as Cavendish himself acknowledged. Warltire next fired mixtures of common air and inflammable air in a closed copper globe, using weighed quantities, with the object of determining the currently debated problem of whether or not heat had weight, and on clearing the globe with a draught of air from a bellows for the next experiment, he 'observed a smoke escape along with it.' Priestley, that intrepid experimenter, had, however, told Warltire that he thought it safe to use glass vessels, and squared his practice with his preaching by making such experiments in Warltire's presence. Warltire followed suit and 'observed, as you [Priestley] did, that though the glass was clean and dry before, yet, after firing the air, it became dewy. . . .' (*Experiments and Observations*, Birmingham, 1781, ii, pp. *396–7). The letter describing these results is dated 18th April, 1781.

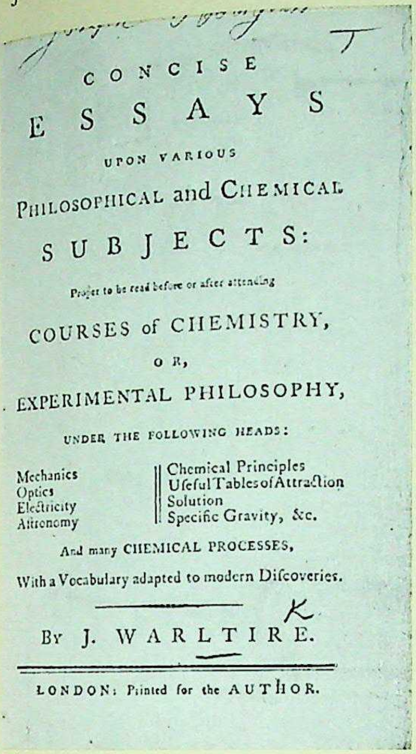
Priestley, in commenting (1781) on this observation, wrote: 'I must add, that the moment he [Warltire] saw the *moisture* on the inside of the closed glass vessel . . . he said that it confirmed an opinion he had long entertained, viz. that common air deposits its moisture when it is phlogisticated' (*ibid.*, p. *398). Priestley shared this view.

The dew was afterwards identified by Cavendish as plain water. His explanation of its production differs little, if at all, from that of Warltire and Priestley, since he supposed that it was deposited from both gases, the common air and the inflammable air, into the composition of both of which it entered as water.

An acute observer, a good experimenter, a successful lecturer, the friend and associate of Priestley, Cavendish, Erasmus Darwin, Wedgwood, and others, Warltire played no mean part in eighteenth-century chemistry. Search over many years, involving many fruitless inquiries, has brought to light a few details of his life.

According to family tradition, Warltire was of Greek descent, and came to England in early life as a refugee from religious persecution. His publications, and other sources, show that he was an itinerant lecturer in natural philosophy.

On 22nd November, 1762, John Warltire, then aged twenty-three, a bachelor, living in the parish of Wolverhampton 'for the space of four weeks last past', was party to a marriage bond and took the oath relating to his marriage by licence on



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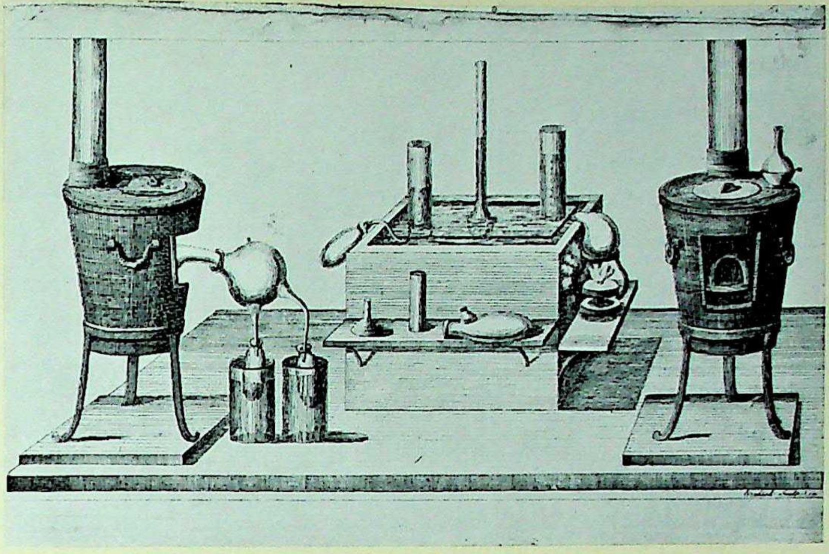

FIGURE 1 – *Title-page of the* Concise Essays (*London,* c. 1775), *with an accompanying illustration of apparatus.*

ANALYSIS
Of a COURSE of
LECTURES
IN
Experimental Philoſophy;
With a brief Account of the
Moſt neceſſary Inſtruments uſed in the Courſe,
AND THE
Gradual Improvements of SCIENCE:
Intended chiefly for the Uſe of the Author's Audience.

By *JOHN WARLTIRE,*
Lecturer in PHILOSOPHY.

The FIFTH EDITION.

EXETER:
Printed, for the Author, by R. TREWMAN,
behind the Guildhall. 1767.

FIGURE 2 – *Title-page of the* Analysis (*Exeter,* 1767), *with accompanying illustrations of apparatus.*

that date in the parish church of St Peter, Wolverhampton, to Mary Stringer, minor, and a spinster of the same parish, daughter of William Stringer. The marriage bond and affidavit are preserved in the Diocesan Registry, Lichfield. This gives Warltire's year of birth as 1739, or possibly 1738. One of the still unsolved difficulties in tracing details of Warltire's life is that no place of residence has so far been found on any relevant document. The old parish of Wolverhampton was much larger than the present parish of that name. Some letters by Warltire seem to have been written from Birmingham, and there is a tradition that he was a partner with Keir in a glass-works at Stourbridge or Wordsley.

Warltire early took to lecturing and writing on science. Already in 1766, when he was twenty-seven, a fourth edition (the only copy of any edition so far traced) of his *A Short Account of the Solar System; Air and Atmosphere; Electricity; and of such Instruments as are necessary to make Experiments, particularly to explain and demonstrate those Sciences. Intended chiefly for the Use of such Ladies and Gentlemen, who attend the Author's Lectures upon those Subjects*, was published in London. This 'fourth edition' may not indicate a great circulation; it seems probable from a consideration of his other works that Warltire had books printed in connection with his lectures, and that when he lectured a new title-page was used after being set up by a local printer. All Warltire's books are now rare.

Another work by Warltire was *Concise Essays upon Various Philosophical and Chemical Subjects: Proper to be read before or after attending Courses of Chemistry, or, Experimental Philosophy*, etc. (London, no date). The British Museum Catalogue suggests 1770 for the date of publication, but as dephlogisticated air, which was not isolated until 1774, and was not so named by Priestley until 1775, appears in the text, the book cannot be earlier than 1775. A later edition of the *Concise Essays*, etc., was published in Nottingham in 1781. Other books include *Analysis of a Course of Lectures in Experimental Philosophy; with a brief Account of the most necessary Instruments used in the Course, and the Gradual Improvements of Science: Intended chiefly for the Use of the Author's Audience*, etc. (Exeter, 5th edn., 1767; London, 6th edn., 1769); *Tables of the Various Combinations and Specific Attraction of the Substances employed in Chemistry. Being a Compendium of that Science: Intended chiefly for the Use of those Gentlemen and Ladies who attend the Author's Lectures*, etc. (London, 1769); *A Course of thirteen Lectures upon General Chemistry; including the Theory and Experiments agreeable to the latest Discoveries* (a syllabus of the course, without place or date of publication); and *Synopsis of Natural and Artificial Chemistry* (without place or date of publication, mentioned by H. C. Bolton in his *Bibliography of Chemistry*, and the only work named here not seen by the writer). All these books seem to have been printed in the places where Warltire lectured: some bear the words 'Printed for the Author.' The *Course of thirteen Lectures* states that 'Subscribers pay One Guinea for the Course and may send Substitutes. Non-subscribers pay 2s. 6d. for every Lecture they attend.'

Warltire was well known to Priestley in 1774, as we have seen. In 1774 or 1776 Erasmus Darwin invited his help in experiments on the cooling produced in the receiver of an air-pump on evacuation; the experiments were reported much later in the *Phil. Trans.* (1788, **78**, 43), where Darwin described Warltire as 'a celebrated itinerant teacher of natural philosophy.'

Warltire gained recognition among his scientific contemporaries. On 2nd October, 1782, he was elected an honorary member of the Manchester Literary and Philosophical Society; his name appears in the list in the first volume of the Society's *Memoirs* (1789). Honorary members were such as had distinguished themselves in the various fields in which the Society was interested, and were resident at some distance from Manchester and so unable to attend the meetings. Warltire was one of the forty-five honorary members; his colleagues included John Aikin, John Coakley Lettsom, Magellan, Priestley, Benjamin Rush, Samuel Foart Simmons, Volta, Wedgwood, Martin Wall, Vic d'Azyr, Erasmus Darwin, Benjamin Franklin, Richard Watson, and Lavoisier. Warltire's name appears in the lists up to 1790, but not later.

A few other details of Warltire's life have been gained from certain letters preserved in the Assay Office, Birmingham, and the Wedgwood Museum, Barlaston. We quote from these by the courtesy of the Assay Master, Birmingham, and Messrs Josiah Wedgwood and Sons.

On 28th September, 1776, Priestley wrote from Calne to Matthew Boulton: 'I take the liberty to recommend to you Mr Warltire, who [has] been sometime in this part of the [cou]ntry, and who is going to read Lectures on the subject of *air* at Birmingham. I think him an excellent philosopher, as well as a modest and agreeable man. He is perfectly acquainted with his subject, and has prepared a set of experiments which have given the greatest satisfaction wherever he has been. He has been so obliging as to spend some time with me, and has given me much assistance . . .' (MS., Assay Office, Birmingham).

We quote next from the draft of a letter to Warltire of 5th February, 1779, in Wedgwood's own hand: 'I was very unlucky & much mortified in being from home when you did me the favor of a visit at Etruria but hope for better fortune another time. Your favor of the 27th ultimo was duly rec^{d} & would have been replied to sooner but I wish'd to be thoroughly satisfied of your having a tolerable subscript^{n} here before I ventur'd to give you any encouragement to come amongst us, & though I am now fully convinced of there being sufficient subscribers to make up your number & I apprehend many more yet some gentlemen . . . think you would have more company about midsummer, perhaps two courses instead of one, as several will now be in town & others taken up with field diversions. Having thus stated the case to you as it appears to me it must remain with you to determine whether you will visit us about the 20th inst. or defer giving us that pleasure 'till midsummer. In either case I have not the least doubt of your meeting a handsome subscription but believe you would be better attended at midsummer.' (MS. E. 18875-26, Wedgwood Museum.)

Evidently Warltire elected for the earlier date; for Wedgwood wrote to Thomas Bentley on 17th February, 1779, to say that 'Mr Warltire comes here on Saturday next to give us some instruction, & as my neighbours seem determin'd to receive it only three days in the week it will make it long before I shall have the pleasure of seeing you at Turnham Green.' (MS. E. 18877–26, Wedgwood Museum.) On the 25th of the same month, Wedgwood wrote again to Bentley: 'Mr Warltire open'd his lecture on Tuesday with a subscription of about 30 Guineas, and I think he will have more. Doct^{r} Darwin has sent his son Rob^{t} to attend the course, & my Jack & this young Doct^{r} is to be have both taken the infection very kindly. They both attend Mr Warltire every morning for private instruction which is of much greater consequence to them than the public lectures.' (MS. E. 18878-26, Wedgwood Museum.)

A later letter of 8th March, 1779, from Wedgwood to Bentley, stated that Warltire had used one of Martin's 'solar microscopes' in his lectures, and that this had led to the exhibition of cameos by its means, and to proposals for its wider use in exhibiting other works of art, the solution and precipitation of metals, crystallization, animalculae, and the circulation of the blood. (MS. E. 18882-26, Wedgwood Museum.)

In September 1781, Warltire gave a course of lectures at Chesterfield. Matthew Boulton, writing to Watt on the 25th, said: 'We stopped again at Chesterfield . . . I found Mr Warltire there teaching Chymical Philosophy to the Chesterfieldians.' (Boulton MSS., Birmingham Reference Library.)

On 19th June, 1784, Christopher Gullett wrote from Beerferris to Matthew Boulton at Truro, referring to some assays by 'your worthy Friend Mr. Warltire,' and quoting an extract from a letter by Warltire from Topsham, written on 24th May, 1784, to the Rev. W. Radcliffe of Plymouth, giving assays of lead ores containing a large proportion of silver. (MS., Assay Office, Birmingham.)

The last detail of Warltire's active life that we have been able to trace refers to a 'Course of ten lectures on the most interesting parts of Natural Philosophy' given at Rotherham in 1803, when he had been 'a lecturer for about 50 years on these subjects.' (H. McLachlan, *English Education under the Test Acts*, Manchester, 1931, p. 203.)

One announcement of a course of lectures by Warltire has been traced. It appeared in the *Exeter Flying Post* for 10th April, 1767, and stated: 'A Course of Experimental Philosophy; at Mr Castiglione's in Gandy's Lane, Exon; to begin on Monday the 13th of April at four in the afternoon. By John Wa[r]ltire.'

Warltire died in Tamworth and was buried on 23rd August, 1810. He was described as 'a tall dark-complexioned man, with long black hair, and a pale face.' It was said that in his early life he had lived among the Arabs, but the most alarming experience that befell him occurred in the lonely moorland district of Morridge, when he was travelling on horseback from Bakewell to Leek. His account of this blood-curdling adventure formed the basis of a local story by Roger Rochcliffe, which appeared in the *Leek Times*. It rivals the adventure of Denys and Gerard among the murderous robbers in the inn in *The Cloister and the Hearth*. (*Olde Leeke*, ed. M. H. Miller, reprinted from and published by the *Leek Times*, 1900, second series, pp. 217–20.)

The writer is greatly indebted to the many correspondents and librarians who have helped him to trace these details, especially to Mrs G. Warltire; Councillor W. Tildesley; Mr Westwood, Assay Master, Birmingham; Mr A. E. Dodd, M.Sc.; and to the never-failing and generous assistance of the former City Librarian of Birmingham, Mr H. M. Cashmore, F.L.A.

The birth and growth of a volcano

FREDERICK H. POUGH

The study of volcanoes, both extinct and active, has proved a fruitful source of information both about the deeper layers of the earth and about the forces which have shaped its crust. It is, however, unique for a volcano to have been kept under close observation almost from the day of its birth, and for this reason the story of Parícutin is of exceptional interest.

In February 1943 the world's preoccupation with more important events reduced the impression made upon the public, and upon geologists, by the appearance of a new volcano in a Mexican cornfield. Eight years have passed, and continuous eruptions from the original small crater have now piled up a sizeable cinder cone, while many square miles of former fields and forests are buried deep under many feet of lava. The new volcano was named Parícutin, after the nearest Indian village, and lies near the centre of the State of Michoacan, about 200 miles south-west of Mexico City.

This spot is but a few miles from the western edge of the high Mexican plateau, and the elevation of the base is about 8200 feet. The cone rises approximately 1600 feet above the base, though its total height appears somewhat less because of the submergence of several hundred feet of the original structure in the flood of lava which laps its flank. In its early stages the cone grew rapidly, but increasing size and steadily diminishing explosive activity have slowed its growth, so that the final elevation will probably not be much greater than that which it now has.

The belt in which it lies is a band of volcanic products overlying a basement of sediments and granitic rocks. The great volcanoes of Mexico punctuate the belt, the greatest of all, Orizaba, marking the eastern edge. Popocatapetl and Ixtaccihuatl vie with each other for tourist attention near Mexico City, and Colima perches on the Pacific border. Smaller volcanic structures dot the intervening countryside; the smallest and most numerous are the thousands of cinder cones which lie on every hand. Parícutin is just another cinder cone. Geologically speaking, it was to be expected, just as its predecessor Jorullo, born in 1759, was to be expected, and as Parícutin's successor of an unknown number of years hence is equally certain to appear. Though many peaks are deeply weathered (Ixtaccihuatl no longer shows a crater) seismically and volcanically, the Mexican volcanic belt is still very much alive. Within its geological limits are textbook examples of several types of volcanic structure.

At the time of Parícutin's birth it was, of course, impossible to make any accurate estimate of the probable duration of its activity. It grew very rapidly at first, and within a few weeks had attained a height of several hundred feet. By May 1943 it was 1000 feet high, forming a beautifully symmetrical cone about 1000 feet across at its summit and over half a mile through at the base. The frequent and violent explosions from the crater made a magnificent spectacle. After the first few weeks, the original character of the activity—largely an ejection of bombs (lumps of molten rock) and lava shreds unaccompanied by fine material—changed, and the eruptions for the next few years, with irregular but recurrent reversions to the earlier type, were characterized by tremendous quantities of solid material, ranging from a light grey powder to coarse lapilli. All the immediate countryside was smothered by this ash, and within half a mile of the cone the deposits attained a depth of 20 feet. Since the prevailing winds of the dry season blow from the north-east, the deposits were not uniformly distributed around the cone, but piled higher and spread further south and west of the vent. A reversal of the winds during the rainy season with normal, minor, fluctuations produced heavy ash deposits all around the cone, slowly thinning out to a thickness of a few inches at ten miles or more from the source.

The forests immediately surrounding the volcano are mainly pine and oak. They were adversely affected by the ash, and the pines soon turned yellow; those near the cone died within a year. Oaks proved to be somewhat more resistant and kept sprouting new growths repeatedly, but in time they too succumbed. Several factors were involved, of which the most important was probably an abrasive and clogging effect of the ash-coating on the leaves. A secondary and slower agent was the deeper burial of the roots, which reduced the vitality of the already severely affected trees. Pine branches near the cone were stripped of bark, and their upper surfaces were worn as if sandpapered.

In addition to the upper surface abrasion of the falling ash there was an additional complication from the blowing dust. During the dry season, from November to June, the sun shines daily on bare fields covered with a thick layer of light, loose, and very fine rock-dust. Local heating makes strong convection currents which race across the field, picking up the powder and blowing it here and there across the country. On such days, life near the volcano becomes very trying. The clouds of dust in the air often obscure all objects more than a score of feet from the observer.

Supplementing the ash, and contributing largely to the mass of the cone, is the much coarser material ejected from the mouth of the crater. The bombs which form the framework of the cone are sometimes numerous, and may, rarely, measure two yards across. Most of them seem to have been solid when they were ejected; indeed, some may have been shot from the vent repeatedly and fallen back into the crater several times before achieving a trajectory which let them descend on the sides of the cone or beyond its base. As a result, their shaping often appears to be largely mechanical; it may even be that in their milling about at the bottom of the crater's funnel they have ground off some of the fine dust that towers so high above the cone. The viscous character of the lava, together with its fairly low temperature, has prevented a marked development of the characteristic oval bombs that are the classic types of volcanic ejecta. Even though they have whirled over and over in the air and then charged like racing fireballs down the side of the cone, their exterior is little shaped by the rotation. Many of them shatter on impact; they seem to be under strain, for they fracture easily, and very few show any sort of crust.

Sometimes, after a brilliant evening burst of hot and fluid lava, one does find bombs showing something of the shaping that is usually expected. Some of these rare bombs have even more liquid interiors, and crack as they strike, to emit a little comb of glassy needles along the line of the fissure. Such bombs were always rare, and were produced only at times of intense crater activity, when great bursts of red, liquid rock were seen rising up and spreading out as they fell in showers that silhouetted the cone in fire. Another type of bomb was elongated and striated, suggesting that the material had been squeezed out of an irregular opening before ejection, much as toothpaste assumes the cross-section of the aperture from which it escapes. As with most of Parícutin's lava, the high viscosity permanently preserved the shapes on cooling.

Occasional bombs were composed of granitic rock, which was encased in a shell of basalt. These presumably represent some of the underlying crust through which the lava had risen. The earliest bombs of this type were almost white, quite fresh, and comparatively unaltered in their outward appearance. In thin section, some bits of intergranular glass and a start of remelting could be noted. In time, the granitic bits became more and more altered, eventually giving place to a frothy white pumice, but remaining discrete as distinct acidic drops in a basalt magma. One of the last fragments of the pipe-wall that was found had been so thoroughly remelted that it was transformed into a grey, streaked obsidian, which fell on the cone in a rind of plastic basalt. Before cooling, the basalt peeled back, splitting a clinging wedge of brittle grey glass into a row of separated teeth along a basalt jaw. Bombs of granitic material are no longer produced by Parícutin; they were common only in the earliest days, and never amounted to more than a very small proportion of the total ejecta.

Great quantities of lava have escaped continuously in a long succession of flows from numerous vents flanking the cone. A single orifice was situated half-way up the side of the cone; all the others have been lower down, nearer to, or well outside, the base. They have been explained as originating on two parallel fault lines running from the north-west to the south-east, and the variously named mouths have lain along these lines. In particular, the original lava flows came from the main vent or from very near it, and were able to transport on their surface some of the material of the cone itself. Such loose masses were carried as much as half a mile away from the spot where they grew, to form three-hundred-foot mounds; these would be very hard for another generation of geologists to explain except as secondary cones with collapsed craters, had their formation not been observed. Some of the suspect descriptions of parasitic mounds around Jorullo can possibly be better interpreted in the light of these observations. Despite repeated destruction of the sides of the cone by escaping lava flows, the cone up to now has been able to repair itself.

After several years it is still almost symmetrical, although higher at the moment on its north-west side, but still growing and still maintaining a classic outline.

In latter years, the lava vents have been further from the cone, and hence have not affected the symmetry so greatly. Their lives as lava springs appear to be long. A western group of vents was continuously active for four years; the present vents on the south-east started early in 1948, and are still producing lava to feed the flows.

There have been no major changes in the lava or its behaviour since the start. The earliest lava immediately assumed the appearance of a great wall of tumbling blocks, the centre fluid, but very viscous, and the periphery enough cooled to be brittle. After about a year, it was noted that the average flow-temperature seemed to be slightly higher—sufficiently higher for the freshly exposed lava to drip off in a sticky mass after a face had crumbled away. Since the vents of most of the early flows were concealed beneath cone debris, the more liquid character of the lava at its point of escape could be observed only occasionally. The first liquid flow was of brief duration and occurred in June 1943. After a few hundred yards of rapid advance, this material stiffened and became blocky. In February 1944, the new series of vents that opened on the north-west side of the cone showed fine fountains at the vents, bubbling with sludgy, but liquid, lava for a period of several weeks. This lava flowed like heaving mud, forming large black curds on the surface which finally jammed and came to rest after travelling fifty feet or so. The still liquid lava beneath flowed on, carrying a welter of shattered black rocks on its surface, and gradually spread outwards into a great lava pool with a broadly advancing front. The front, however, was of the typical solid blocky type. Truly liquid red lava became visible at a distance from the vents only when a tongue was advancing rapidly down a gulley, as in the case of the flow which finally invaded the town of San Juan de Parangaricutiro, three miles away in a direct line but much more by the downhill route sought out by the lava stream.

The long San Juan stream, which has travelled farthest of all from its source, is marked, now that it has solidified, by more ashy lava than that of the other flows. Its surface shows an anastomosing pattern, as if the invading tongues had squeezed out of many crevices instead of coming down as the usual blocks. The greater quantity of gas indicated by the open texture of the cooled lava may explain this difference in its behaviour, and its greater extension. The quantity of gas accompanying the lava has notably diminished with time. At the end of the advance, the earliest flow-fronts were still fuming moraines long after all the movement had ceased. Each gas vent was lined with snowy crystals of ammonium chloride, with an occasional seasoning of mustard-coloured iron ammonium chlorides. Magnificent specimens of these water-soluble minerals could be collected around the crevices during the dry season; in fact, specimens could be produced to order by digging out such a vent and inserting suitably sized rocks for a few days of sublimation. The recent lava flows have been marked by no such line of guiding beacons, and ammonium chloride is now practically unobtainable in mineral specimens.

Hotter gases which form no collectable sublimates escape from the surface of the active flows. The advance of a lava stream at Parícutin, unlike those from volcanoes where the lava is more liquid, is not exactly like that of water. The initial flood of lava may spread over a large area, where most of it becomes stagnant and frozen. In time, the current becomes canalized, and while the main flow is dead, a narrow line of current stays alive. Its route can easily be charted by the line of blue fumes which hover along its path. Sometimes surfaces crusted solidly, and in March 1944 it was possible to walk almost at will over a flow that was still alive and flowing beneath our feet. The gas caught with this lava was responsible for two interesting phenomena, the development of small gas vents, known as hornitos, and the faint blue flames which flickered nightly above such orifices.

Hornitos or 'little ovens' sprang up on the surface of the crust over such a flow wherever a leak developed—a crack from which gas could escape with vigour, forcefully enough to blow out small fragments of black, melted, metallic-looking, highly reduced lava. In time, these shining building-stones piled up around the vent to form a glass chimney which might rise several feet in the air. The lining of these pipes was incandescent. Gusts of rising gas made the liquid inner surface flow upwards, welding the pile of fragments into a solid tube. At night, blue flames could be seen swaying above these vents, presumably caused by burning hydrogen set free by the reducing action of the filtering rock on the highly heated water vapour passing up through them. From time to

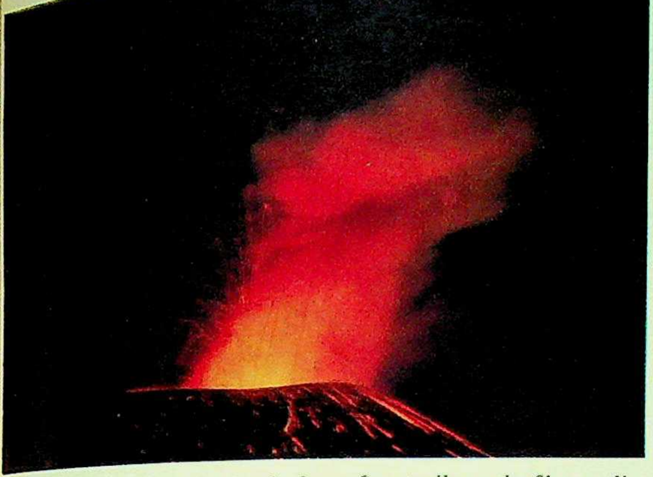

FIGURE 1 – *Incandescent bombs leave fiery trails on the film, outlining the cone against the evening sky. Only at dusk and after dark can the glow of the bombs be seen; by day they look black.*

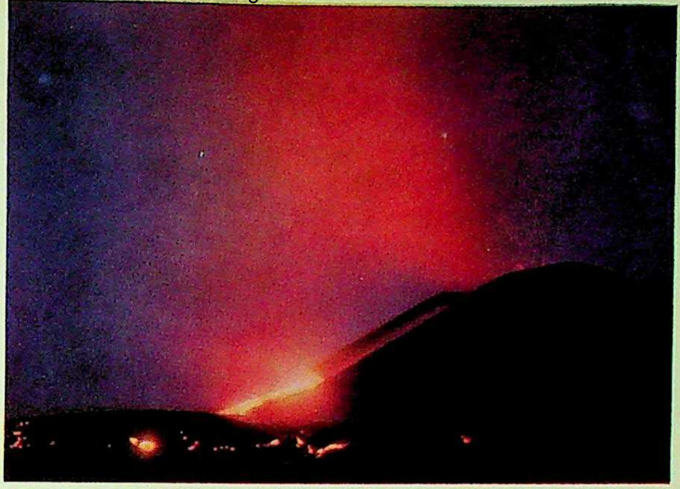

FIGURE 2 – *Recent activity has robbed the crater of much of its explosive force. Lava is escaping on the flank and showing incandescence only near the vent and at the crumbling front.*

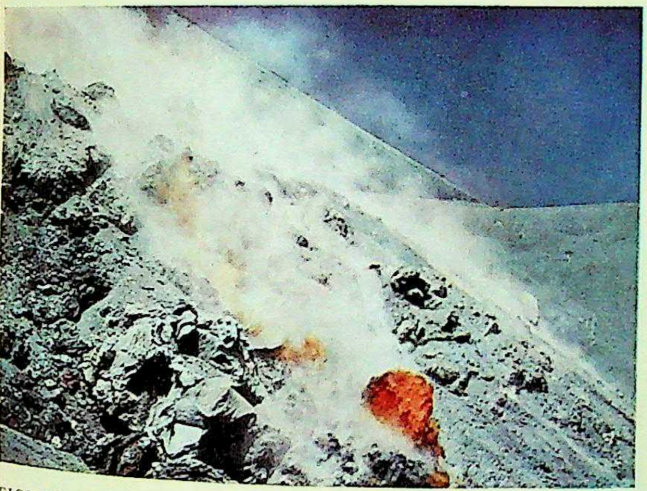

FIGURE 3 – *The viscous lava cools to brittleness and advances as a crumbling twenty-foot wall of hot loose stones, each freshly broken surface glowing redly for a few brief moments as the blocks tumble downwards.*

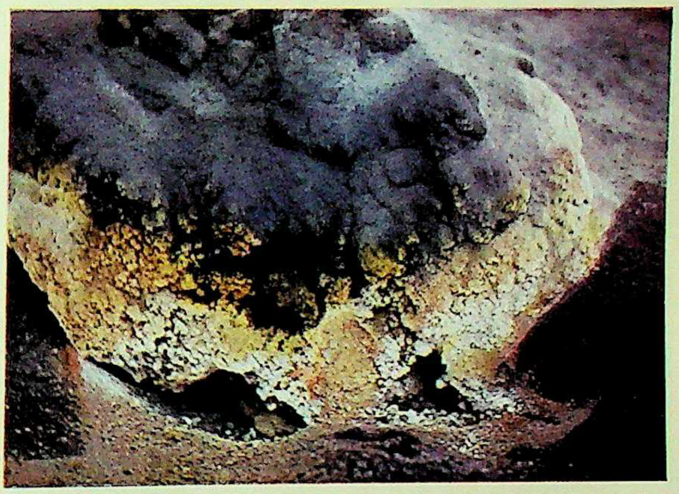

FIGURE 4 – *Trapped gases escape from frozen flows months after all movement has ceased. Around each hot fumarole colourful water-soluble salts form, ammonium and iron chlorides crystallizing directly from the gas at temperatures between 200 and 500° F.*

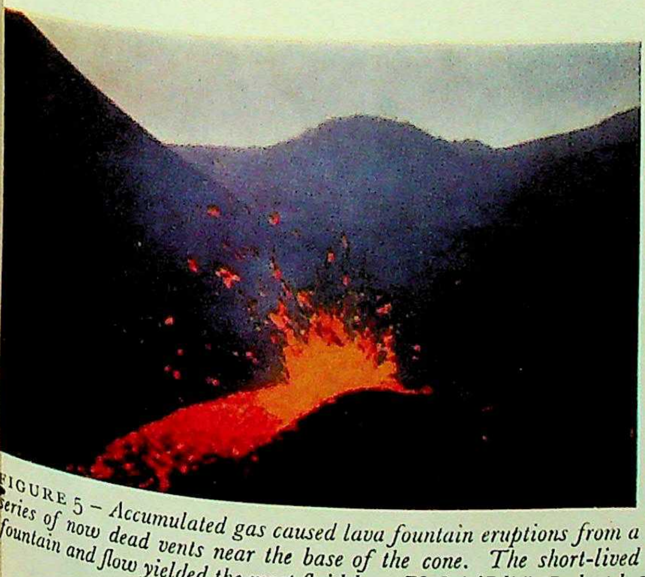

FIGURE 5 – *Accumulated gas caused lava fountain eruptions from a series of now dead vents near the base of the cone. The short-lived fountain and flow yielded the most fluid lava Paricutin has produced.*

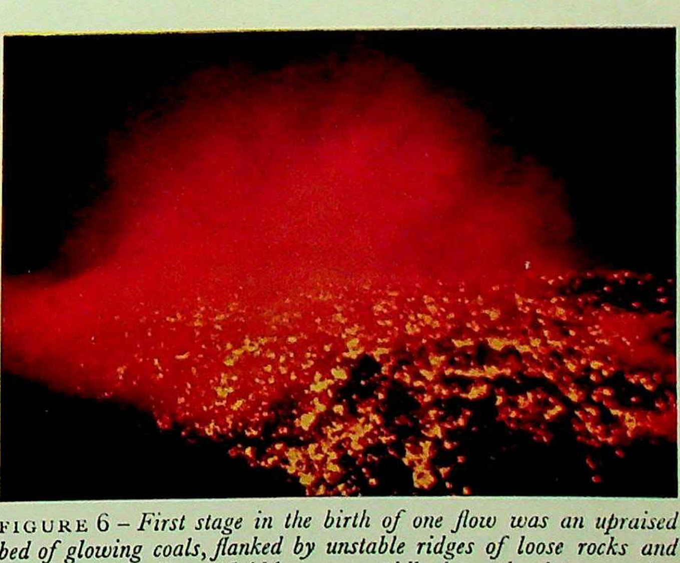

FIGURE 6 – *First stage in the birth of one flow was an upraised bed of glowing coals, flanked by unstable ridges of loose rocks and ash. On their collapse, fluid lava ran rapidly down the slope, covering several hundred yards in a matter of minutes. Movement in the ridge as this picture was taken gave warning that it was not a safe place for a prolonged stay.*

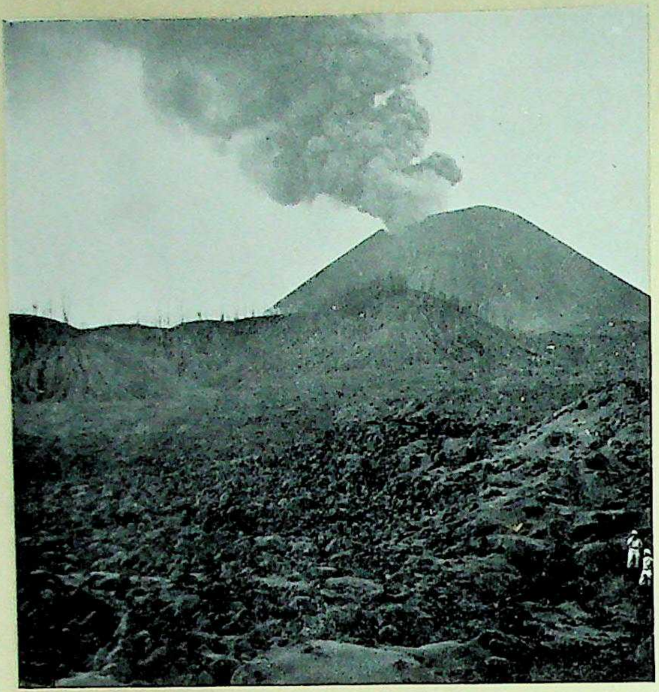

FIGURE 7 – *Exaggerated erosion characterizes the tree-covered slopes of the old, half-buried hills on which the dead trees still stand, stripped of their needles and of all value as conservators of the soil.*

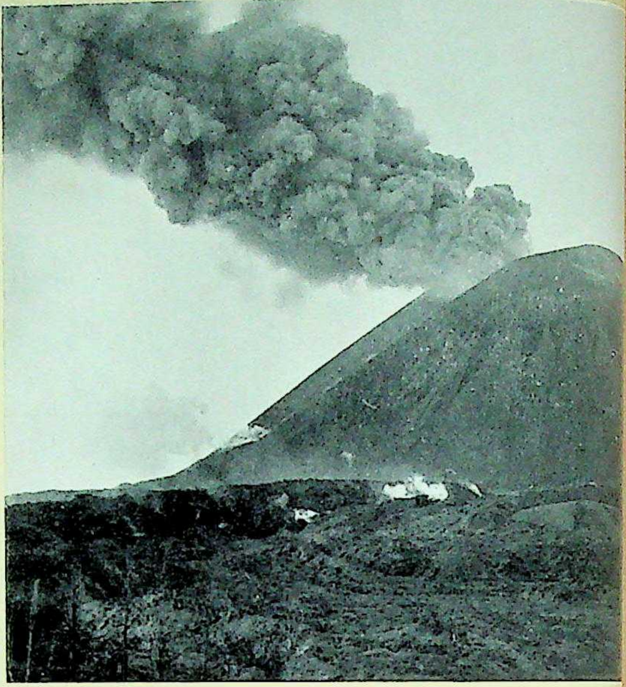

FIGURE 8 – *The ash-covered 'window' in the lava flow represen the top of the old hill formed from a rafted fragment of the c still exposed in 1948 but covered over by the 1950 flows.*

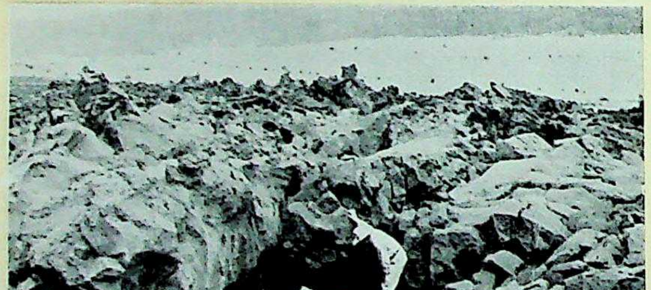

FIGURE 9 – *A cave in the distinctive San Juan lava flow marks a spot where the liquid interior escaped to leave an arched opening in the flow as the hardened surface buckled and cracked open.*

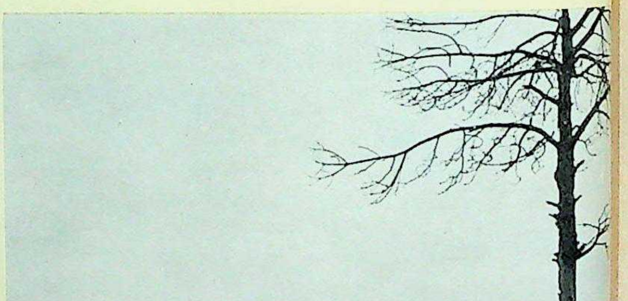

FIGURE 10 – *Deeply buried but still living pine trees framin surviving church façade in the San Juan lava flow in 1948. W another year the trees gave up the struggle.*

time—only once when human observers were present—a great quantity of gas, with an accompanying rush of well-fluxed lava, would produce thin minor lava-streams from a cluster of such vents. The lava escaped in the form of a series of spectacular fountains which rose in solid columns 40 feet into the air.

The visitor who goes to Parícutin today, after its nearly eight years of progressively changing activity, will see a spectacle somewhat different from that which excited the early viewers. Those who have not been there before still find it the most thrilling experience of their lives: even in its senility it presents an impressive spectacle. The dust column now drifts out like chimney smoke, instead of rushing upwards and outwards in a five-mile tower of doom. Occasionally a great explosion will hurl numbers of bombs a mile from its base, but the few that usually accompany today's explosions roll harmlessly down its side, to collect around the base. The lava escapes quietly for the most part, flowing imperceptibly down from a vent which it has lifted some three hundred feet in the air. Only an occasional snort shows that it might yet do better things. Lava fountains have not been observed for over a year. The night view is lovely: incandescent fragments describe their graceful arcs through the sky, and from time to time are numerous enough to limn the cone in fire. Near the base the lava cascade glows as a sinuous ribbon, and a mile beyond, at the present lava front, a bright spot shines momentarily as a block falls out to expose a fresh face. The advance of the lava front is very slow.

It is difficult to predict what the future holds for Parícutin, or, at least, to predict when it will become quiescent. Probably its present activity gives the clue to its future behaviour. Certainly, the quantity of gas that has accompanied the emission of lava has diminished. The explosions are much milder and less frequent. From time to time the activity seems to stop entirely, now for only a few minutes at a time, but the interval could easily grow longer and longer. The rate of lava production fluctuates similarly, but in total it, too, appears to be diminishing. Everything points to a gradual running down of the activity, with, in the foreseeable future, a final cessation of all eruptions.

Book reviews

MEDIEVAL MINING AND ASSAYING

Bergwerk- und Probierbüchlein, *translated from the German by Anneliese Grünhaldt Sisco and Cyril Stanley Smith, with technical annotations and historical notes. Pp.* 196, *with illustrations. The American Institute of Mining and Metallurgical Engineers, New York.* 1949. $5 *net.*

This book, like the handsome translation of Biringuccio's *De la Pirotechnia* issued under the same auspices in 1942, has been published with the aid of the Seeley W. Mudd Memorial Fund. It is an English translation of two medieval booklets first printed early in the sixteenth century. The *Bergbüchlein,* or 'Little Book of Ores,' and the *Probierbüchlein,* or 'Little Book of Assaying,' were the first printed works dealing with aspects of mining and metallurgy respectively. As antecedents of the celebrated works of Biringuccio and Agricola they are of considerable historical interest, particularly as Agricola drew freely upon them in writing the classical *De Re Metallica.* The *Bergbüchlein* was intended as an introduction to mining geology for the use of beginners, whereas the *Probierbüchlein* was a collection of recipes and working directions for established artisans. Both books ran through many editions, and their complicated bibliography is discussed at some length with the help of many reproductions of the illustrated title-pages. The views of the *Bergbüchlein* on the generation of ores were purely alchemical, but there is much sound practical information on technical terms, tools, and the nature and associations of various ores. The *Probierbüchlein* is of an eminently practical nature, with accounts of such subjects as balances and weights, sampling, assay by touchstone, furnaces, crucibles, cupellation, assay of ores, and various methods of parting. The work of translation and editing has been accomplished admirably, there is a useful index, and the book is beautifully printed and produced.

JOHN READ

INTRODUCTION TO BIOLOGY

Biology, An Introduction to Medical and other Studies, *by P. D. F. Murray. Pp.* 600, *with numerous line drawings and half-tones. Macmillan and Company Limited, London.* 1950. 25*s. net.*

This long and very interesting book has been written for all students of biology, but especially for medical students, for whom the author has tried to provide a text which will correlate their first-year studies with those that follow.

This admirable intention is well maintained throughout the book. Beginning with unicellular animals and plants, the author takes us, in the course of 24 chapters, through the morphology of plants and animals, emphasizing, by means of the ferns and the frog, the invasion of the land, and, by means of the flowering plants and the rabbit, the conquest of it. Chapters on man and the mammals complete this section and precede four chapters on the cell and vertebrate tissues, and nine on embryology and evolution. In this latter section the chapter on causal embryology, which describes important experiments and the conclusions to be drawn from them, is a useful lesson in experimental method applied to the problem of finding out how the complex adult animal develops.

The author's broad outlook is well expressed in the chapters on development, and in the ten chapters on growth, behaviour, and animal and plant physiology. The book ends with six concise chapters on fungi, bacteria, viruses, parasitic animals and plants, and symbiosis.

A valuable feature of the book is its wealth of excellent line and half-tone illustrations. Many of these are new and all are very well done. Some chapters, notably those on the vertebrate tissues, are given just those additional illustrations which communicate real understanding to the reader.

The style is clear and pleasant to read. This book is neither a dull statement of facts nor a book on elementary zoology mechanically shuffled into a book on elementary botany. It is botany and zoology integrated with one another, and with other branches of science, to make an attractively written, well-printed book which can be read with pleasure and understanding.

G. LAPAGE

COSMIC PHYSICS

Cosmical Electro-Dynamics, *by H. Alfvén. Pp.* 237, *with various line diagrams. Oxford University Press, London.* 1950. 25*s. net.*

The publication of Professor Alfvén's book coincides with great developments in cosmic physics, and is a most welcome and timely addition to the literature. The first chapters give excellent accounts of the motion of charged particles in magnetic fields, and of the fundamental features of electric discharges in gases, with particular reference to the conditions in interstellar space. In 1942 Alfvén postulated the existence of a new type of wave arising when hydrodynamic motion occurs in an electrically conducting medium situated in a magnetic field. The chapter devoted to these magneto-hydrodynamic waves is of great value and interest. The chapter on solar physics occupies nearly one-third of the book, and Alfvén seeks to explain many solar phenomena such as sunspots, prominences, and the high temperature of the corona, in terms of the magneto-hydrodynamic theory. The fundamental requirement for the success of these theories is that the sun possesses a general magnetic field. It is unfortunate that in the short time since the book was written opinion has markedly hardened against the existence of such a general solar field. Nevertheless, the chapter contains a wealth of data about solar conditions, and is of the utmost value. The last two chapters are devoted to magnetic storms and aurorae, and the origin of cosmic rays. These are perhaps the least successful part of the book, owing to the severe restriction of treatment. The aurora is treated as an electric field effect, and the cosmic ray energies are considered to arise by acceleration in the fields due to a double star generator. Although these explanations are perfectly plausible, the book would have gained in value from a further treatment of the alternative views which are currently held.

A. C. B. LOVELL

ORGANIC REACTIONS

Organic Reactions. Volume V. *Editor-in-Chief, Roger Adams. Pp. viii* + 446. *John Wiley and Sons, New York; Chapman and Hall Limited, London.* 1949. 48*s. net.*

Organic Reactions is now a standard work of reference. It furnishes a wealth of information about many organic reactions, with regard both to the practical details of their application and to the various compounds to which they have been applied.

Volume V deals with the following topics: the synthesis of acetylenes; cyanoethylation, involving the addition reactions of acrylonitrile; the Diels-Alder reaction as applied to quinones and unsaturated ketones; the Schiemann reaction for the preparation of aromatic fluorine compounds from diazonium fluoborates; the Friedel-Crafts type reaction with aliphatic dibasic acid anhydrides; the Gattermann-Koch reaction; the Leuckhart reaction, the reductive alkylation of amino compounds by aldehydes and ketones; oxidation by means of selenium dioxide; the Hoesch ketone synthesis; and the Darzens glycidic ester condensation, i.e. the production of an αβ-epoxy ester from a carbonyl compound and an α-halogen ester.

The reviewer ventures to suggest that, as the separate chapters are written by experts, they might on occasion add to the value of their articles by going beyond a statement of the scope of the reaction and the cataloguing of its applications. Perhaps a little more space might be devoted to discussions of reaction mechanisms, and opinions as to further applications of the reactions would be welcome. The usefulness of these reactions may be taken for granted; improvements are likely to result only from an appreciation of their limitations. The very high standard of the articles in previous volumes is maintained in Volume V.

W. BAKER

AMINO ACIDS AND PROTEINS

Amino Acids and Proteins—Cold Spring Harbor Symposia on Quantitative Biology. *Pp.* 217, *with numerous half-tone and line illustrations. The Biological Laboratory, Cold Spring Harbor, U.S.A.* 1950. $7 *net.*

This report of the symposium maintains the tradition of its well-known predecessors, which is to put on record for those interested in the various aspects of a particular field of investigation a series of authoritative summaries of the latest work. The chapters are not arranged in a logical sequence, but the field is nevertheless well covered. Amino acids are considered from the point of view of their analysis by chromatographic and isotope dilution methods, and of their biosynthesis and metabolism. Articles also deal with the rapidly expanding subject of the metabolism and synthesis of peptides, and with the application of counter-current techniques for their separation and as a test of homogeneity. Just over half the chapters, however, are concerned with the fantastically complicated problems posed by the intact proteins. These include their chemical reactions, physical properties, methods of fractionation, and, of course, hydrolysis. Further reviews cover the problems of protein structure with special reference to insulin, that great friend of man which is surely going to be the first protein to be graced with something like a structural formula. The book has many examples illustrating the American genius for lucid illustration, and altogether it makes exciting reading out of a subject so easily made to appear dull and uninteresting.

C. E. DENT

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

AGRICULTURE

D.D.T. and Newer Persistent Insecticides (*2nd edition*), *by T. F. West and G. A. Campbell. Pp.* 632, *with* 13 *half-tone plates. Chapman and Hall Limited, London.* 1950. 50*s. net.*

BIOLOGY

The Actinomycetes, *by Selman A. Waksman. Pp.* 230, *with various line and half-tone illustrations. The Chronica Botanica Co., Waltham, Mass.; Wm. Dawson and Sons Limited, London.* 1950. $5 *net.*

Man is a Microcosm, *by J. A. V. Butler. Pp.* 151, *with various line and half-tone illustrations. Macmillan and Company Limited, London.* 1950. 10*s.* 6*d. net.*

New Biology—No. 9. *Pp.* 128, *with various half-tone illustrations. Penguin Books, Harmondsworth.* 1950. 1*s.* 6*d. net.*

Principles of Human Genetics, *by Curt Stern. Pp.* 617, *with line and half-tone illustrations. W. H. Freeman and Company, San Francisco, California.* 1949. 41*s. net.*

BIOGRAPHY

Jan Ingenhousz, Plant Pathologist, *by Howard S. Reed. Pp.* 396, *with several half-tone illustrations. Chronica Botanica Co., Waltham, Mass.; Wm. Dawson and Sons Limited, London.* 1950. $3 *net.*

BOTANY

Die Chromosomenzahlen der Gefässpflanzen Mitteleuropas, *by George Tischler. Pp.* 256. *Dr W. Junk, The Hague.* 1950. *Fl.* 42.50 *net.*

CHEMISTRY

Analytical Absorption Spectroscopy, *edited by M. G. Mellon. Pp.* 618, *with numerous half-tone and line illustrations. John Wiley and Sons, New York; Chapman and Hall Limited, London.* 1950. 72*s. net.*

Chemical Society—Annual Reports, 1949 (Volume 46). *Pp.* 333, *with line diagrams. The Chemical Society, London.* 1950. 25*s. net.*

College Chemistry, *by Linus Pauling. Pp.* 705, *with various line drawings and charts. W. H. Freeman and Company, San Francisco, California.* 1950. 34*s. net.*

Physical Aspects of Organic Chemistry, *by W. A. Waters. Pp.* 539, *with various line diagrams. Routledge and Kegan Paul Limited, London.* 1950. 35*s. net.*

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ENDEAVOUR

A quarterly review designed to record the
progress of the sciences in the service
of mankind

VOLUME X April 1951 NUMBER 38

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A British whimsy

Britain is an island—a geographical fact possessing both advantages and disadvantages for the islanders. The twenty-mile gap of salt water which separates Dover from Calais has proved an invincible defence for nearly a thousand years, but it may also have acted as a barrier to ideas. Insularity in itself is not necessarily a drawback, and no one could accuse Britain of paucity of inspiration, yet an island folk is prone to develop idiosyncrasies to which it is blind, however plain they may be to onlookers. We may sigh, with Robert Burns, 'O wad some Pow'r the giftie gie us To see oursels as ithers see us!'

It is probably true that one of the chief oddities of recent British culture is the attack made from time to time by classicists upon science: the uncharitableness—perhaps not all upon the one side —may lie latent for a while, but, like an epidemic disease, it flares up now and again with greater or less virulence. A recent outbreak, well ventilated in the British press, showed so little appreciation of the spirit of science that it is worth scrutiny and rebutment.

Put shortly, the argument of the classicists was that science has little, if any, educational value, and that the only valid basis of education is the study of Latin and Greek language and literature. Some of the classicists had the comfortable logic that an educated man is one who knows Latin and Greek, and that therefore Latin and Greek are essential to education—a begging-the-question surprisingly prevalent but of course usually disguised in agile verbosity.

One wonders whether the classicists fully realize the implications of their thesis. Ancient Egyptian astronomers invented the calendar; Urukagina, Gudea, and Hammurabi established comprehensive codes of law; and Hindu poets had shaped the Rigveda by 1000 B.C.—yet all these must be regarded as uneducated men inasmuch as they were ignorant of Latin and Greek. Even Shakespeare, with his 'small Latin and less Greek,' could have been at best only half educated. The thesis is, in fact, palpably absurd when considered as absolute. There is more to be said for it, however, from a relative point of view, but perhaps we may first consider why many British classicists are so intransigent in their attitude towards science.

The intransigence is not very deep-rooted; it is mainly a product of the nineteenth century. To Newton, the idea of an inimical opposition between classical learning and science would have appeared meaningless, but signs of the approaching rift came with Joseph Priestley, who wrote 'Let it be remembered that a taste for science, pleasing, and even honourable as it is, is not one of the highest passions of our nature, that the pleasures it furnishes are even but one degree, above those of sense, and therefore that temperance is requisite in all scientifical pursuits.' The learned Dr David Hartley was more severe. 'Nothing,' he says, 'can easily exceed the vain-glory, self-conceit, arrogance, emulation, and envy, that are found in the eminent professors of the sciences. . . . Temperance in these studies is, therefore, evidently required, both in order to check the rise of such ill passions, and to give room for the cultivation of other essential parts of our natures.'

The Industrial Revolution brought about a further hardening of thought. Science became more and more involved with trade, and though Victorian England was fully alive to material benefits it maintained a rigid distinction between tradesmen and gentlemen—tradesmen had even to call at a gentleman's house by a special entrance. Gentlemen educated their sons at the great public schools—'public,' in this case, by one of the inconsistencies of the English language, meaning private—and the education was almost entirely classical. Science did not begin to form a part of the curriculum until the latter half of the century, and was very slow to establish itself. 'I am afraid we now have to teach science,' a former headmaster of a well known public school is reported to have said when showing parents the new school laboratories, 'but we still manage to produce gentlemen.'

Other factors contributed to the somewhat contemptuous recognition of science, not the least of them being the repugnance aroused in pious minds by Darwin's *The Origin of Species* and *The Descent of Man*. Many worthy Englishmen sincerely felt that if science shook fundamental beliefs it should be avoided as a plague, and the repercussions of this feeling struck far and wide. There was also a curious incredulity as to the practical possibilities of scientific discovery. It is true that the great exhibition of 1851 was partly designed to display scientific achievements, but many years later the famous English statesman, Gladstone, said to Faraday at the Royal Institution (so the story goes): 'This invention of yours is very interesting, Professor Faraday, but what is the use of it?' Faraday replied, with quiet humour, 'Sir, there is every probability that in a few years' time you will be able to tax it.' The story may not be true, but it is indicative of an attitude common in nineteenth-century Britain.

It is against such a background that we must view the British classicists' disparaging opinions of science. No one is likely to dispute the educational value of Latin and Greek, for classical culture forms so great a part of our intellectual heritage; our thought is still largely moulded by Athens and our administration by Rome. Yet the sum of human knowledge has increased immeasurably since Horace led a pleasant life at his Sabine farm and Aristotle accompanied Alexander on world conquest: it can no longer be maintained that in Plato and Sophocles, in Ovid and Virgil, the twentieth century can find all the mental sustenance it requires. 'I have taken all knowledge to be my province,' wrote Bacon to Lord Burleigh, and that surely should be the maxim for everyone who aspires to be considered educated. Classicists who know nothing of science are as imperfectly educated as scientists who know nothing of the humanities; neither should be satisfied with their enthusiasm for one particular subject, for by being so they miss the poise and graciousness of life. And, indeed, as was well said by Arthur James Balfour, 'it is unfortunate, considering that enthusiasm moves the world, that so few enthusiasts can be trusted to speak the truth'—a remark that applies as much to scientists pleading for science as to classicists pleading for the classics.

It is a fact that most of our leading British men of science have displayed an interest in, and a knowledge of, the humanities which is far from being at odds with their scientific training. Indeed, their training in science seems often to have awakened their minds to the values inherent in the legacy of Greece and Rome: is it too much to hope that our humanists may gradually come to recognize that the same values, in different aspects, exist also in the realm of science? The ecstasy of Keats in poetic creation, the 'dark passion' of Mozart, the quintessential delicacy of Botticelli, are all to be paralleled in Faraday's delight in a successful experiment, Rutherford's delineation of the structure of the atom, and Kelvin's lifelong satisfaction in the result of an acute piece of reasoning.

There is a great passage which provides the answer to the question as to what constitutes a liberal education. It runs as follows:

'That man, I think, has had a liberal education, who has been so trained in youth that his body is the ready servant of his will, and does with ease and pleasure all the work that as a mechanism it is capable of; whose intellect is a clear cold logic engine, with all its parts of equal strength, and in smooth working order; ready, like a steam engine, to be turned to any kind of work, and spin the gossamers as well as forge the anchors of the mind; whose mind is stored with a knowledge of the great and fundamental truths of nature and of the laws of her operations; one who, no stunted ascetic, is full of life and fire, but whose passions are trained to come to heel by a vigorous will, the servant of a tender conscience; who has learned to love all beauty, whether of nature or of art, to hate all vileness, and to respect others as himself.

'Such a one and no other, I conceive, has had a liberal education, for he is, as completely as a man can be, in harmony with nature. He will make the best of her, and she of him. They will get on together rarely; she as his ever-beneficent mother; he as her mouth-piece, her conscious self, her minister and interpreter.'

Can one elicit from among those who have endeavoured to define a liberal education a finer description of it than this? And the man to whom we owe the description was Thomas Henry Huxley, a leading thinker of the Victorian Age in Britain and one of its most brilliant scientists.

We should be like Bacon, and regard all knowledge as our province, neither extolling one branch nor belittling another. As scientists, we are probably far better acquainted with our shortcomings than our critics are, and many a man of science when examining aspirants has sighed at their all too frequent illiteracy. It could be well argued that in this scientific age an ignorance of letters is certainly no more deplorable than an ignorance of science, but the critics of science are essentially on a crusade for values which they know to be inestimable and fear may gradually be lost. We think that our island classicists not seldom create overseas a wrong impression of British scholarship and the attitude of British scientists towards it. The sporadic outbursts of mutual criticism are not to be taken too seriously: they are merely an example of another British whimsy.

Some results in the field of high-pressure physics

P. W. BRIDGMAN

The investigation of pressures large enough to affect the properties of materials, and now extending up to 100,000 atmospheres, is comparatively recent. It is to Professor Bridgman that we are indebted for almost all our knowledge in this new field. He here describes how such pressures are achieved, and some of the effects they cause. High pressures can create polymorphic forms of numerous substances obtainable in no other way.

In this article I shall describe some of the physical phenomena which are produced in various materials when exposed to high hydrostatic pressures. Pressure is not usually thought of as having any important effect on the properties of materials, and indeed under the ordinary conditions in which human beings live it does not. The effect of temperature is usually far more important for us, for temperature changes may produce such important results as the conversion of ordinary liquid water to solid ice or gaseous steam. One reason for the comparative unimportance of pressure is that the variations of pressure which we can easily produce are, so far as the molecules are concerned, not large. Under pressures which are large for the molecules, changes may be produced quite as drastic as those brought about by changes of temperature. For example, water may not only be frozen solid by the application of pressure alone, but pressure is capable of producing seven different kinds of ice, something which mere alteration of temperature is unable to accomplish.

The pressures which are large enough to affect molecules are in general of the order of thousands of atmospheres, and it is with such pressures that we shall be concerned here. To set the scale, a thousand atmospheres, or some 15,000 lb per square inch, is approximately the pressure at the deepest part of the ocean, produced by a column of water six miles high. Two thousand atmospheres is approximately the pressure in the explosion chamber of a large gun. From the cosmic point of view, the importance of understanding the effects of pressures of this magnitude is obvious, because all except a small fraction of 1 per cent. of the matter in the universe exists under pressures greater than 1000 atmospheres.

In extending scientific measurements into the realm of pressures of this magnitude, various technological problems are encountered. There is in the first place the problem of preventing leakage of the liquid by which pressure is transmitted. This problem may be solved by designing the packing in such a way that the pressure in it is maintained automatically, by the liquid pressure itself, at a level higher by a fixed percentage than that in the liquid. The principle will be clear from figure 1, which illustrates the packing on the end of a piston by which pressure is generated. A piston packed in this way cannot leak, so that all one needs to do to produce any desired pressure is to push the piston into the pressure vessel with the necessary force. The force driving the piston is most advantageously obtained from a hydraulic press or some other form of hydraulic intensifier.

'Any desired pressure' is, however, obviously subject to several limitations, in particular the strength of the containing vessel and of the piston. It might perhaps be thought at first that the strength of the containing vessel could be increased indefinitely, merely by making the walls of the vessel of unlimited thickness. This unfortunately is not so, for even an infinitely thick vessel has only a finite strength. The reason for this is that stress and strain are concentrated at the inner parts, so that the outer parts do not do their proportionate share in supporting the pressure. In practice, it turns out that the limit for heavy cylinders of the best heat-treated steels is about 15,000 atmospheres; this may be increased for brief operations to 20,000 or more. Still higher pressures can perhaps be achieved by shrinking hoops on to the vessel, as in a well known method of gun construction, but even with such vessels the upper limit yet reached, in some experiments by Newitt, is in the neighbourhood of 30,000 atmospheres. While the pressure vessel is reaching its limit the piston also is reaching its limit, the upper limit

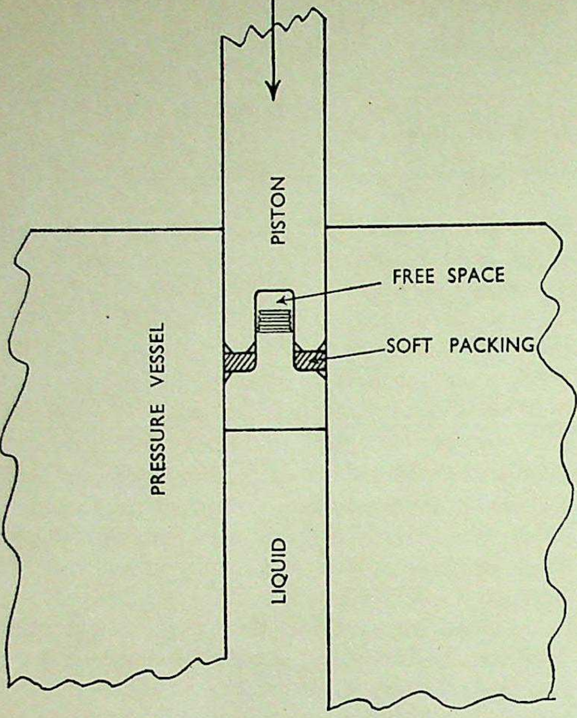

FIGURE 1 – *Application to a piston of the principle by which the pressure in the packing is automatically maintained at a pressure greater by a fixed percentage than the pressure in the liquid. Leaks therefore cannot occur.*

for the compressive strength of any steel now available being also in the neighbourhood of 30,000 atmospheres.

To reach higher pressures, a radical change in design is necessary. For the piston, however, it is sufficient to change the material of which it is made to Carboloy, which has a compressive strength more than twice that of the best steels. Carboloy is a product of powder metallurgy, and is a sintered aggregate of tungsten carbide cemented with a small amount of cobalt as binder. To obtain greater strength in the pressure vessels more elaborate methods are necessary. In all my experiments it has involved giving the pressure vessel some sort of external support to counteract the effect of the internal pressure. The simplest way of doing this is to make the vessel conical on the outside surface and to push the entire pressure vessel into a conical supporting sleeve as internal pressure increases. The vessel may be pushed into its sleeve in various ways. The simplest is to let the thrust which drives the piston drive the vessel also into its sleeve; a method of doing this is indicated in figure 2. Alternatively, the pressure vessel may be forced into its sleeve by an independent hydraulic press coupled in the proper ratio to the press which produces the internal pressure. The choice of method depends on the size of the apparatus, and is determined by various factors such as friction, which we cannot discuss here. The limit to the pressures which have been used in the laboratory in apparatus constructed with conical external support has been about 50,000 atmospheres. At this pressure a new limiting effect appears: this is the incipient extrusion of the pressure vessel through the supporting sleeve by the thrust, or some other sort of fracture of the vessel due to the thrust.

To reach yet higher pressures, the vessel must receive still more effective support. This may be given by immersing the pressure vessel in a liquid which is itself exposed to high hydrostatic pressure. In this way the pressure vessel receives complete support over its entire external surface. This proves effective enough to extend the range from 50,000 to 100,000 atmospheres. The external supporting pressure necessary for this extension may be between 25,000 and 30,000 atmospheres.

So large an extension of range, from 50,000 to 100,000 atmospheres, by a supporting pressure of only 25,000 atmospheres, would not be possible if it were not for the change in the properties of steel and Carboloy produced by a pressure of 25,000 atmospheres. Under this pressure, steel becomes much more ductile and also stronger. Carboloy becomes stronger in compression and loses its brittleness, so that Carboloy pistons can be subjected to pressures of 100,000 atmospheres or even more. Carboloy also increases in tensile strength, so that the pressure vessel itself may be constructed

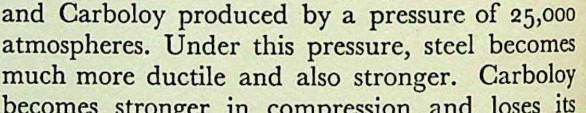

FIGURE 2 – *Simple method of giving external support to a pressure vessel by using the thrust on the piston which produces internal pressure to push the whole vessel into a supporting conical sleeve.*

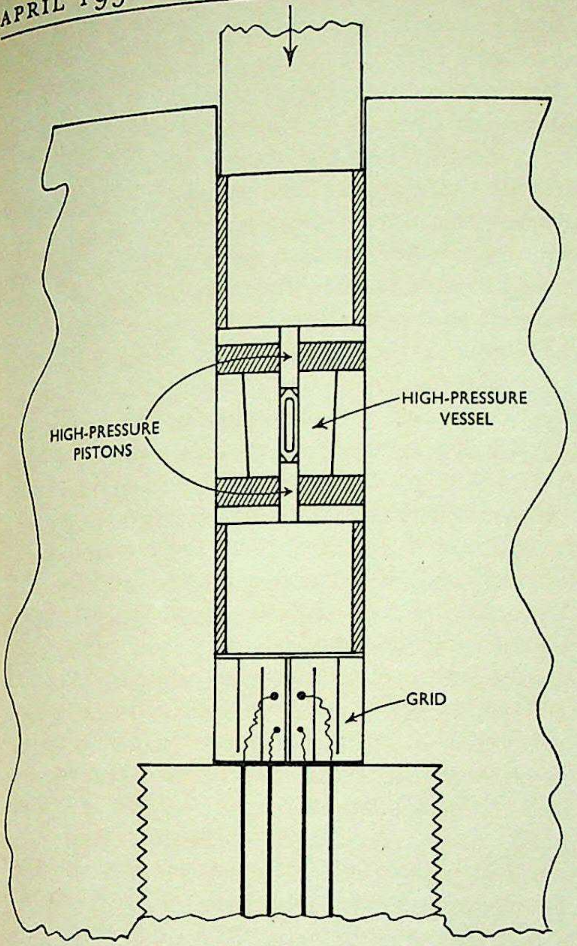

FIGURE 3 – *Diagram of apparatus by which pressures of 100,000 atmospheres can be realized. The high-pressure vessel is completely immersed in a liquid (shaded) which is itself subjected to pressure and thus supports it. The thrust on the high-pressure pistons is determined by measuring the change of electrical resistance of the 'grid' which receives the thrust.*

of this material, supported on the outside by a shrunk-on steel jacket. The apparatus is indicated schematically in figure 3; it is in fact an arrangement of one pressure vessel inside another. Theoretically, any extension whatever of the pressure range would be possible by this method, by making a nest of pressure vessels, each one containing a successively higher pressure supporting the vessels within. Although theoretically possible, no feasible method of constructing more than the first apparatus in such a series has been found.

It may appear paradoxical that at these very high pressures the problem which at first restricted experiments, namely the problem of preventing leak of the pressure-transmitting medium, has entirely disappeared. The reason for this is that at these pressures fluids no longer exist; all normal liquids or gases are frozen solid by the pressure. All the elements ordinarily gaseous, except helium, have been solidified at 50,000 atmospheres, and there is good reason to think that at 100,000 atmospheres helium too freezes solid. In this region, pressures have to be transmitted by soft solids and can be only approximately hydrostatic. Fortunately there are soft solids, such as tin or preferably indium, of which the plastic shearing strength is low, so that pressure fails to be hydrostatic by only a few per cent. It is, however, not so easy to find a solid insulator which is sufficiently yielding at 100,000 atmospheres to be also a good pressure transmitter.

For every successive increase in the pressure range a price has to be paid in a diminution in the size of apparatus, which in turn limits the sort of experiment that can be made. The vessel in which a pressure of 100,000 atmospheres is generated is, on the inside, only 1·6 mm in diameter and 1·8 mm long. In this apparatus, volume changes can be measured with fair precision, and the volume changes of a large number of substances have been determined. Still higher pressures can be reached, but, at this stage, on a scale so small that little research of scientific value has been done. The principle by which these higher pressures may be reached is that used in making hardness measurements by pressing a Brinell ball or a diamond cone into the material being tested. Stresses very much higher than normal may be supported over small areas if the surrounding material is unstressed and so can support the highly stressed region. With an arrangement of this sort, in which a short Carboloy cone is pressed against a flat Carboloy block, the whole combination being mounted within a chamber at 30,000 atmospheres so that there is additional support by hydrostatic pressure, pressures in excess of 400,000 atmospheres have been realized at the point of contact of the cone. However, not much use can be made of these very high pressures, except to achieve the negative result of showing that certain transformations that might perhaps be expected are not in fact produced. In particular, graphite is not transformed into diamond by such a pressure at room temperature, although it is the thermodynamically stable form.

All the pressures mentioned so far have been static pressures. Dynamically, as in the explosion of shaped charges, it is possible to reach very much higher pressures, measured in millions of atmospheres. This is doubtless the ultimate method of getting high pressures (except by use of atomic bombs), and a beginning is now being made. The difficulties, however, to say nothing of the expense, are immense, and progress will probably be slow. The problem of measuring the pressures and temperatures reached by such methods is itself an exceedingly formidable one, and for the present the only method seems to be to extrapolate results obtained by static methods in lower ranges. Thus the results that can be obtained by the static methods outlined above will probably continue to have their usefulness for some considerable time.

Having now discussed the various methods of achieving high pressures we may turn to a consideration of some of the effects produced. The simplest of these effects, although by no means the simplest to measure, is the diminution of volume which all substances suffer under pressure. A general feature of the volume-changes produced by hydrostatic pressure is that they are reversible, so that when pressure is released the volume recovers its original value. In other words, there is no elastic limit or fracture point. This is strikingly different from what happens when change of shape is produced by the application of powerful forces other than hydrostatic pressure. Most apparent exceptions can be explained by the closing of flaws in the materials. There are some other apparent exceptions, due to a phase of greater thermodynamic stability than the original being produced by pressure. In such cases, however, the new phase created shows no permanent change when pressure is again applied and released. The reason for the failure of hydrostatic pressure to produce permanent changes is to be sought in the atomic constitution of matter. The specific volume of a substance depends only on the nature of the atoms (or molecules) of which it is composed; neglecting isotopes, there is only one kind of iron atom, for example, not one kind before it has been compressed and another kind afterwards. This suggests that if pressures could be applied which were high enough to change the atoms themselves we might expect permanent changes of volume. Ordinarily, however, atomic transmutation is not brought about by pressure only, and we therefore have perfect volume elasticity.

In the realm of terrestrial pressures, within which the atoms remain unaltered, at least three classes of effect must be considered. In the first place there is the gaseous range. Here compressibilities are very high, volume being approximately inversely proportional to pressure. The mechanism is a kinetic one, pressure being exerted by the collision of the molecules with the walls of the container. Pressure is twice as high at half the volume because there are approximately twice as many collisions per unit area of the walls. This effect cannot, however, persist over any considerable range of pressure, because eventually the molecules begin to interfere with each other through being pushed too closely together. When this happens a new effect occurs. Increasing pressure now pushes the molecules progressively more closely together until all the empty spaces between them are squeezed out and the molecules are effectively in contact. This is the sort of thing that occurs in the compression of liquids under ordinary conditions, or in the compression of gases under such high pressures that their density approaches that of liquids. This effect is characterized by a compressibility that falls off rapidly with decreasing volume, for at first the empty spaces can be squeezed smaller with comparative ease, but when the molecules are nearly in complete contact this possibility is greatly reduced. The third effect now begins, namely the deformation of the molecules or atoms themselves after they have been squeezed into effective contact. It is with this that we are primarily concerned in the compression of solids. Modern knowledge of the atom as a system of electrons and nucleus, depicting the atom as consisting almost entirely of empty space pervaded by an intense field of force, makes comprehensible a high degree of deformability under pressure in the atom itself. According to this picture, atoms with the most complicated electronic structures should be capable of a higher degree of compression than those with less complicated structures. This is exactly what is found. For example, nitrogen, in the region in which interference between the molecules begins and the ideal gas laws lose their validity, loses its compressibility much more rapidly than does helium, because the molecules of nitrogen are larger and are more quickly brought into contact. At still higher pressures, however, when the vacant spaces between molecules have been largely squeezed out, nitrogen becomes more compressible than helium, because the molecule of nitrogen is larger and more complex than that of helium, and therefore possesses the possibility of undergoing a greater degree of compression.

It is, of course, to be understood that there is no sharp dividing line between these three mechanisms by which a substance responds to an external pressure by losing volume; at any instant all three mechanisms are present together. It is the relative importance of the three mechanisms which changes with increasing pressure. It has already been suggested that at still higher pressures the atoms themselves may begin to break. As a result of its complex structure an atom may conceivably break in many ways. It is quite possible that what happens may not be anything like as catastrophic and irreversible as the change we ordinarily associate with breaking; it may merely be a rearrangement of the electrons in their orbits, and there is no reason why such a rearrangement should not be reversible. At pressures higher than those yet reached in the laboratory, amounting perhaps to several millions of atmospheres, we may expect all sorts of detailed changes of this kind to be produced in atoms. In the laboratory, two instances have already been found of an inner rearrangement presumably due to pressure. The element caesium, which is the most compressible of the metals, undergoes an abrupt change of volume at 45,000 atmospheres. This change is large—17 per cent.—and there seems to be no explanation for it in terms of the ordinary lattice structure of the metal, because it is highly probable that below 45,000 atmospheres the lattice is already in the close-packed, face-centred cubic arrangement. It would seem that pressure could not make a more closely packed arrangement than one which is already close-packed. The explanation seems to be that a rearrangement of the electronic orbits within the atoms is brought about by pressure. The details have been worked out in a recent paper by Sternheimer; he shows that an electronic transition from a 6*s* zone to a 5*d* zone exactly accounts for all the experimental facts. Metallic cerium is doubtless a similar case; it shows an abrupt volume-change at 7,000 atmospheres, of the same order of magnitude as that which occurs in caesium. In the case of cerium it has been shown by ingenious experiments at the University of Chicago that both above and below the discontinuity the lattice arrangement is the same face-centred, close-packed arrangement. The presumption is therefore again that there must be an inner electronic change, although the theoretical details have not yet been worked out.

In figure 4 the volume-changes of some of the ordinary solid elements are shown as a function of pressure in the range up to 100,000 atmospheres. There is a great variability in compressibility. The most compressible element shown in the diagram is caesium, which at 100,000 atmospheres is compressed to 37 per cent. of its initial volume. The least compressible substance is probably carbon in the form of diamond, which under the same pressure is compressed only to 98·2 per cent. of its initial volume. The diagram indicates that for most substances the loss of volume is far from being linearly related to the pressure; the lines are strongly curved, showing that the compressibility drops off with increasing pressure. This is the same effect as we noted for liquids, but it is on a different and much more extensive scale. It must mean that inside the atom there is some sort of mutual interference between the electronic orbits, analogous to the interference between atoms or molecules which occurs in liquids. The necessity for the non-linearity in the relation between pressure and volume is obvious, for, if it were not so, volumes would eventually become negative at sufficiently high pressure. Thus it can be calculated that if the compressibility of caesium continued at its initial rate, the metal would be squeezed out of existence altogether by a pressure of only 14,000 atmospheres.

Although every volume-pressure curve must eventually be convex toward the pressure axis, there may be an opposite curvature over considerable pressure ranges. There is no mechanical or thermodynamical reason why compressibility should not in some circumstances increase with increasing pressure. Examples of this are in fact known; the most striking is perhaps quartz glass. Its compressibility increases with pressure over a wide range. Such behaviour cannot, however, continue indefinitely, and sooner or later there must be a reversal. Experiment shows that the reversal occurs at a pressure of 35,000 atmospheres, where the volume is still far above zero, being in fact 89·3 per cent. of its initial value. Above 35,000 compressibility decreases in the normal way with rising pressure. The abnormality ceases so abruptly at 35,000 that there is a cusp on the pressure-volume curve. It is as if there were some special mechanism responsible for the abnormality, which abruptly goes out of action at 35,000 atmospheres. A plausible mechanism would assume something in the nature of lenticular cavities in the structure, which are squeezed flat at 35,000 atmospheres.

The pressure-volume curves in figure 4 contain several examples of discontinuities. These are due to transitions of one kind or another. In most cases they are ordinary polymorphic transitions resulting from a change in the crystal lattice. The proof that they represent transitions of this sort is usually indirect and presumptive, but in some instances direct proof can be given. One method is by X-ray analysis of the new phase while it is under pressure. Another is to follow the transition to atmospheric pressure by suitably changing the temperature, and then to establish the nature of the transition at atmospheric pressure by some convenient method not subject to the limitations of high-pressure measurements.

It will be seen from figure 4 that in some cases a substance may show more than one discontinuity. One of the most interesting of such substances is bismuth. At atmospheric pressure, bismuth is abnormal in many ways; in particular it is one of the few substances which, like water, expand when they freeze. Thermodynamics demands that for substances of this sort the effect of pressure should be to lower the melting-point. This effect was found for water comparatively early; the agreement between the experimentally determined and the theoretically calculated lowering of the freezing-point was in fact one of the early triumphs of the then young science of thermodynamics. Much later, I found that the melting-point of bismuth is similarly lowered by application of pressure, as would be expected. What, it may be asked, can we expect to be the ultimate course of the freezing-curve of water as we raise pressure indefinitely? In the case of water, it is found experimentally that, at first, increasing pressure only accentuates the effect, for at higher pressures the abnormal increase of volume on freezing becomes larger, and therefore the melting-point is depressed at a continually accelerating rate. One would expect that this could not continue indefinitely, and in fact it does not. It was Tammann who first found how water extricates itself from its dilemma. At − 22° C and 2200 atmospheres ordinary ice abruptly gives up the unequal struggle and collapses into a new kind of ice, a very large decrease of volume occurring at the same time. In fact, the decrease of volume is so large that the new solid has a smaller volume than the liquid from which it freezes. This means that the melting-point of the new form of ice increases with rising pressure. Not only this, but, as the pressure continues to rise, the new ice discovered by Tammann eventually becomes unstable in its turn and is replaced by a succession of others, with still smaller volumes and more rapidly rising melting-points. In all, seven kinds of ice have so far been discovered. The last of these may be heated without melting to the temperature of melting solder, provided a pressure of 45,000 atmospheres is applied.

By analogy, it was expected that a new kind of bismuth would appear at high pressures to replace the ordinary abnormal bismuth, and that the melting-point of the new bismuth would rise with pressure. Search for this hypothetical bismuth was diligently made by workers in the high-pressure field, but for a long time with no success. Eventually the new modification was found, but at a pressure considerably higher than had been anticipated, namely at 25,000 atmospheres, more than ten times the pressure which produces the analogous transition in ice. Furthermore, there are still other transitions of bismuth at even higher pressures, as there are for ice. Figure 4 shows transitions at 45,000, 65,000 and 90,000 atmospheres, in addition to the one already mentioned at 25,000 atmospheres. In reality, the transition at 25,000 is double, there being two transitions so close together—within a thousand atmospheres of each other—that it would have been confusing to try to separate them in the diagram. Thus altogether there are five known transitions of bismuth, or six polymorphic modifications of the solid. This is the same as the known number of stable modifications of ice, so that the two substances would seem to be quite closely parallel.

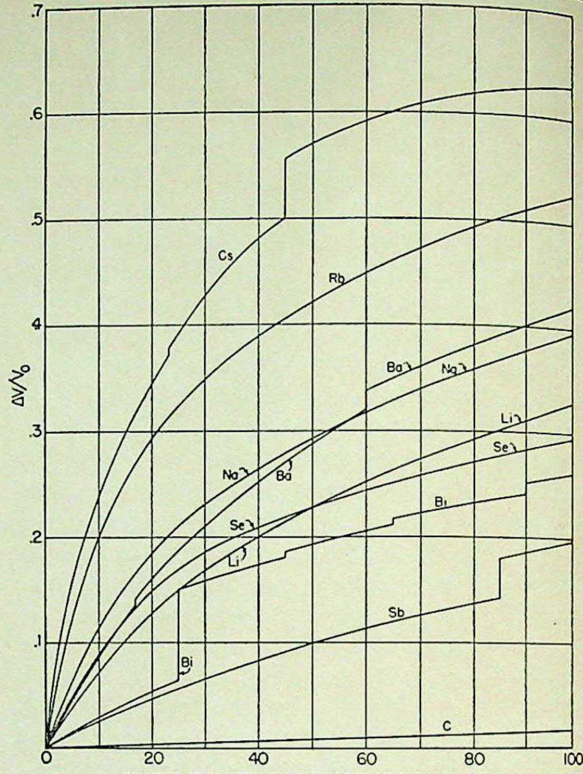

FIGURE 4 – *The change of relative volume of a number of substances shown as a function of pressure up to* 100,000 *kg/cm² (metric atmospheres).*

There are two other fairly well-known elements which, like bismuth, are abnormal in that they expand on freezing. These are antimony and gallium. The same question arises with respect to them: will they also have other modifications under pressure, and will the melting-point curve of the new modification rise instead of fall? Of these two substances antimony is in many respects much like bismuth: chemically it is closely related, and it crystallizes in the same system. Figure 4 shows that it, too, has a transition under pressure but at a pressure more than three times that of bismuth—85,000 atmospheres instead of 25,000. It may well be, therefore, that bismuth and antimony are analogous in their polymorphic behaviour. Proof of this must, however, wait until higher pressures can be commanded in the laboratory, for it would appear that the pressure scale of the phenomena in antimony is more than three times as great as the scale for bismuth. Also the melting-point of antimony is much higher than that of bismuth, so that it has not been possible to find experimentally whether the melting-point of the new antimony is raised by pressure.

The other abnormal element, gallium, proves to fall into line as well, and here the pressure scale is fortunately smaller. A new gallium appears at a pressure of about 12,000 atmospheres, and the melting-point rises with pressure. Gallium and water are parallel in that gallium has a high-pressure modification which is totally unstable thermodynamically with respect to the other modifications; similarly there is a totally unstable form of ice that appears at temperatures below 0° C and at pressures above 4000 atmospheres.

Considering all three substances—water, bismuth, and gallium—it would thus appear that pressure ultimately wipes out the ordinary abnormal forms and they become normal, at least to the extent that their melting-point rises with increasing pressure.

Figure 4 shows another example of polymorphism induced by pressure; barium possesses two transitions and three modifications. Polymorphism is indeed a phenomenon commonly encountered in high-pressure research. Among the several hundred substances that I have examined, about one-third show polymorphic transitions. The phase diagrams of most of these substances have been examined, and it is possible to show how the pressure at which a transition occurs changes with temperature. Study of these phase diagrams reveals that many of the modifications found under pressure are quite new, in that they do not occur at atmospheric pressure at any temperature. Furthermore, there seems to be no tendency for the phenomenon to exhaust itself as the pressure range is increased; on a statistical basis, the probability that pressure will produce a new modification in an unknown substance is proportional to the pressure. The significance of this in geophysics is obvious; it means that the probability is that the materials in the earth's crust occur there in forms with which we are not familiar in the laboratory, and therefore have unfamiliar physical properties. This implies that it is hazardous to infer the composition of the earth's crust from such evidence about its properties as is given by the velocity of propagation of seismic disturbances. Uncertainty with regard to inferences of this sort can be removed only by specific and detailed knowledge.

The transitions discussed thus far have been characterized by thermodynamic reversibility; when the pressure is removed the substance reverts to its original condition, unless by chance it is hindered at comparatively low temperatures by internal viscosity. In addition to these reversible transitions there are a few examples known of essentially irreversible transitions produced by pressure. Here the substance is converted into a new form by the application of pressure; this new form is then permanently retained and is thermodynamically stable when the pressure is removed. The transformation of yellow phosphorus into black by a pressure of 12,000 atmospheres at 200° C is an example which has been known for a long time. The same transition may be made to occur at room temperature by 30,000 or 40,000 atmospheres. At still higher pressures—60,000 atmospheres or so—the more stable red or violet phosphorus may be transformed into the same black variety. Another example is carbon disulphide. This substance, ordinarily a highly volatile liquid, is slowly transformed at 175° C and 40,000 atmospheres into a permanent black solid, denser than the elements from which it is constructed.

The theory of these irreversible transitions is even less well understood than that of the reversible polymorphic transitions, and indeed, as far as I know, no example has ever been worked out theoretically. Until we have some theoretical basis for knowing what to expect, we must contemplate the possibility that any of the materials of daily life can, by sufficient pressure, be pushed over a potential hill into some entirely unknown form possessing new, and perhaps desirable, properties.

The Oxford Botanic Garden

T. G. B. OSBORN

'Amongst the several famous structures and curiosities wherewith the flourishing University of Oxford is enriched, that of the Public Physic Garden deserves not the least place, being a matter of great use and ornament.' So wrote Thomas Baskerville towards the close of the seventeenth century in his *Account of Oxford.* The Garden is the oldest of its kind in Britain.

The Oxford Botanic Garden was founded in 1621 by Henry, Lord Danvers, later Earl of Danby. He, 'being minded to become a benefactor of the University, thought that his money could not be better laid out than . . . by the foundation of a Physic Garden.' In the sixteenth century several such gardens had been established on the continent of Europe, but there was at that time none in Britain. The Oxford Garden is thus the oldest in the British Isles, and its historic interest is enhanced by the fact that it is still on the original site and enclosed by the original, magnificently gated, walls erected by the munificence of the founder. The site chosen by him was a piece of riverside meadow about five acres in extent, opposite Magdalen College and just outside the East Gate of the city. The area had been used as a burial ground by the Jews of Oxford until their expulsion in 1290. It came into the possession of Magdalen on the foundation of the college in 1458. In 1621 it was held on lease from the college. Lord Danby provided the funds necessary to buy out the sitting tenant and to transfer the lease to the university, which, in respect of this piece of land, has been a tenant of Magdalen ever since.

On the afternoon of St James's Day (25th July), 1621, there was an opening ceremony marked by speeches and the laying of a foundation stone. Thereafter the real work of forming the Garden began. The 'stately free-stone wall' was more than ten years in building. The principal gate, built by Nicholas Stone, bears the date 1632. Fully as important as the enclosure of the Garden must have been the work of raising the level of the ground above the flood-level of the River Cherwell, which forms the eastern boundary. Even today, in times of exceptional floods, pools of water may seep up inside the walls, while portions of the outlying parts may be submerged to a foot or more.

The walled Garden is rectangular, with sides 134 and 117 yards long, enclosing an area of about 3¼ acres. Its first layout, as shown by Loggan's plan (1675), shows it to have been subdivided internally into quarters by hedges, inside which were flower beds arranged according to a geometrical pattern (figure 9). From the first catalogue, published in 1648, we know that more than 1600 different kinds of plants were then in cultivation. Some 600 of these were British and there were also many Canadian, but numerous others were merely varieties and sports. Nevertheless, the bringing together of such a collection within ten years represents much work.

It appears that Lord Danby intended that his foundation should provide for both a professor and a gardener. This arrangement was not completed in his lifetime. He died in 1644, leaving a small endowment for the Garden and having appointed Jacob Bobart, Senior, as gardener in 1641. The terms of the appointment are interesting. Bobart and his heirs were appointed for ninety-nine years, with a salary of £40 for labour and expenses, together with any benefits of produce. This last provision proved most important, for the salary was not paid during the troubled times of the Protectorate and Restoration. There is in the archives of the university a signed, though undated, petition from Bobart's son—also Jacob—to the Vice-Chancellor asking that he may receive a salary, and continuing: 'it is but a melancholy consideration to look back and think (and indeed as great a Wonder) that this should be the only Publick Garden of Europe that hitherto maintained itself.' Bobart refers to the indignity of having to make the market cross at Carfax 'shine with the spoils of the Garden.' No doubt the shilling which Samuel Pepys records against his visit to the Garden on 9th June, 1668, went towards the upkeep, and we may be sure that the 'very good fruit' which John Evelyn and his ladies sampled on 12th July, 1654, was not accepted without some return. In spite of all these difficulties, the Bobarts were cultivating 'exoticks' as well. Evelyn

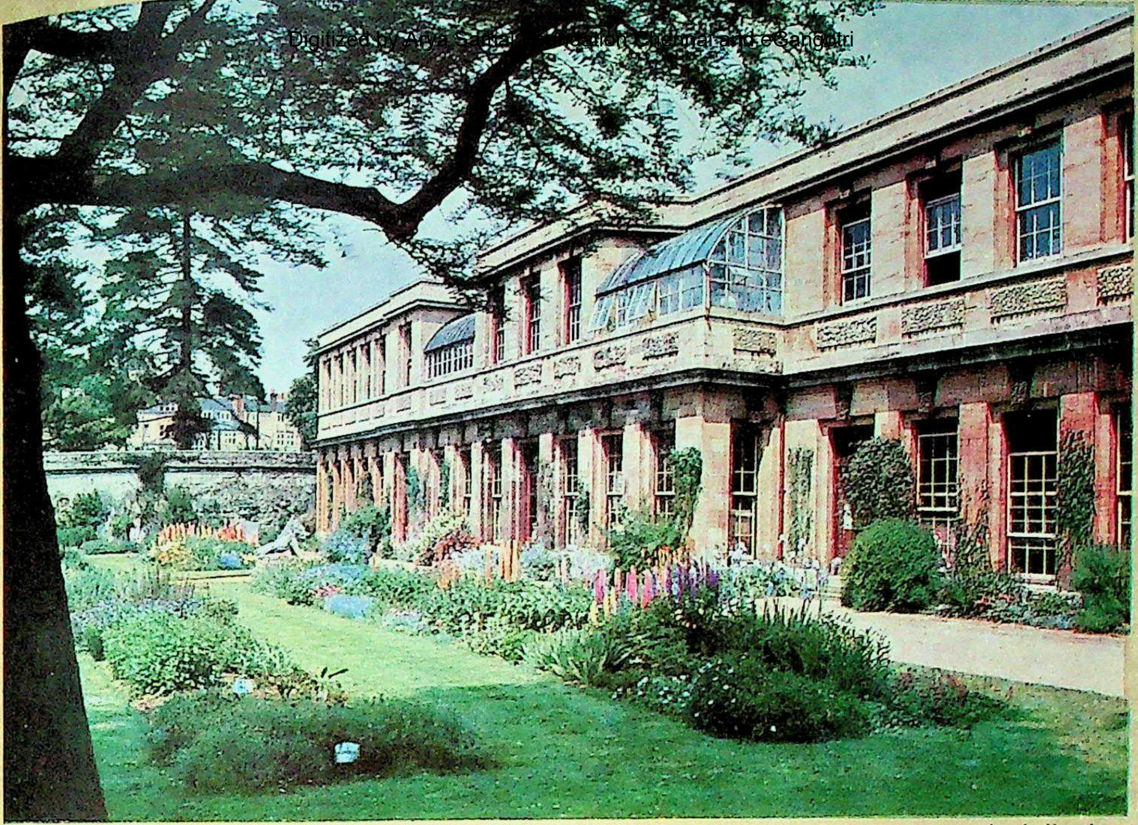

FIGURE 1 – *The western range of buildings facing the Garden, based upon one of the two orangeries built about* 1730. *At present they are the main laboratories of the Department of Botany. To the left is one of the Order Beds containing Labiates. The tree on the left is a swamp cypress* (Taxodium distichum) *planted about* 1840.

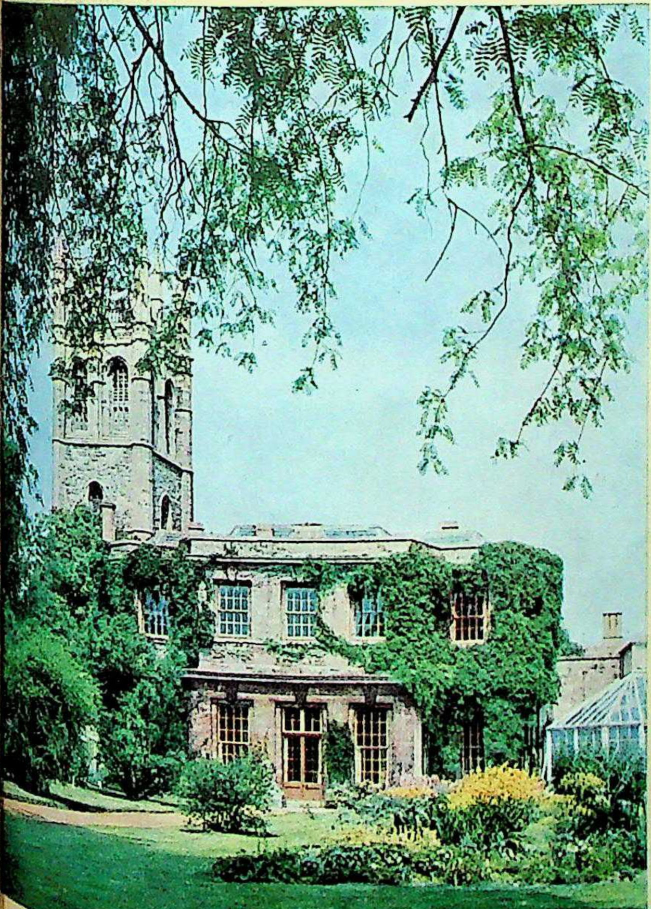

FIGURE 2 – *The eastern range of buildings, with Magdalen Tower behind. The ground floor of this building (at present the library) is the second of the two orangeries erected about* 1730. *The foliage in the foreground is part of the large service tree* (Sorbus domestica).

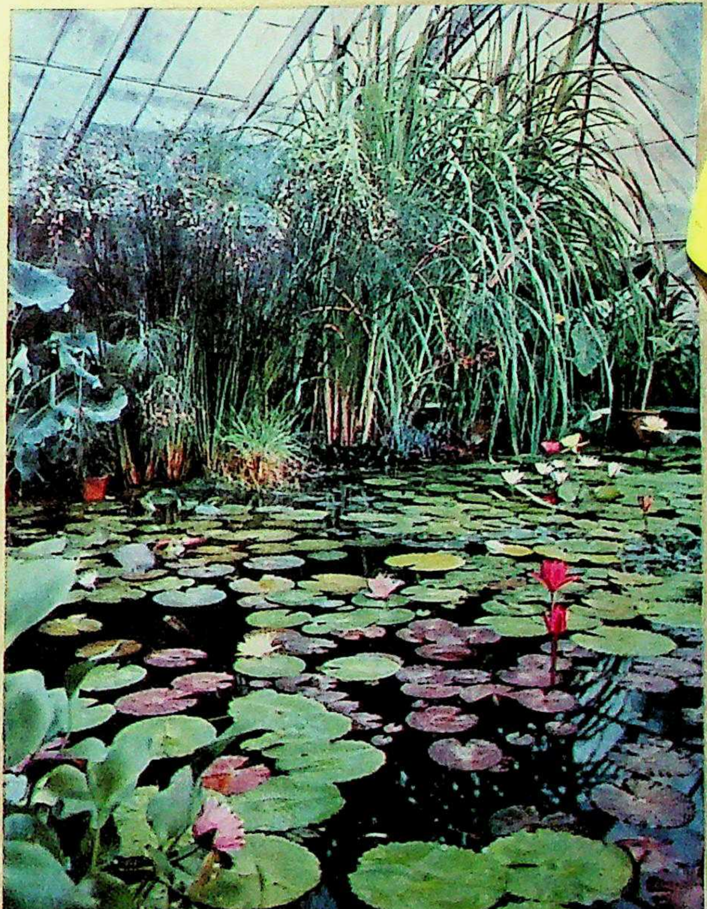

FIGURE 3 – *Portion of the tropical water-lily house. In the background are plants of (left to right) lotus* (Nelumbium speciosum), *papyrus* (Cyperus papyrus), *and sugar cane* (Saccharum officinarum).

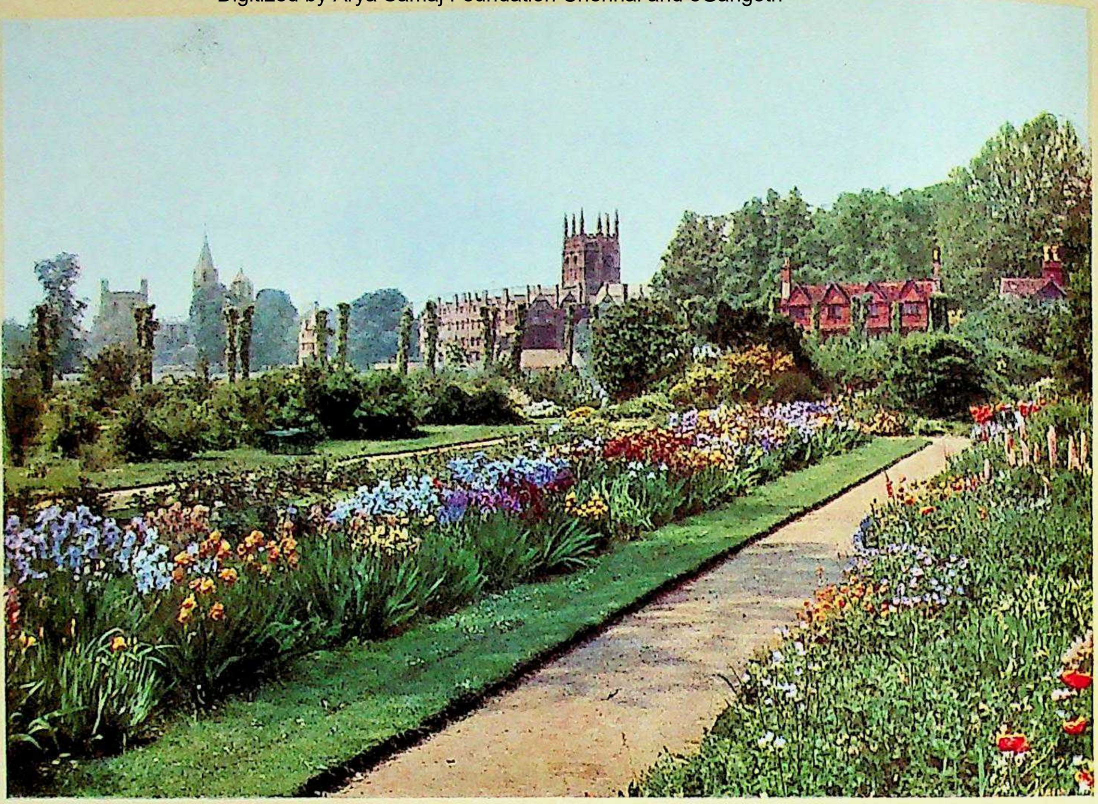

FIGURE 4 – *View outside the walled Garden looking towards Christ Church and Merton College. The left middle distance shows part of the new shrub garden. In front is the collection of hybrid irises.*

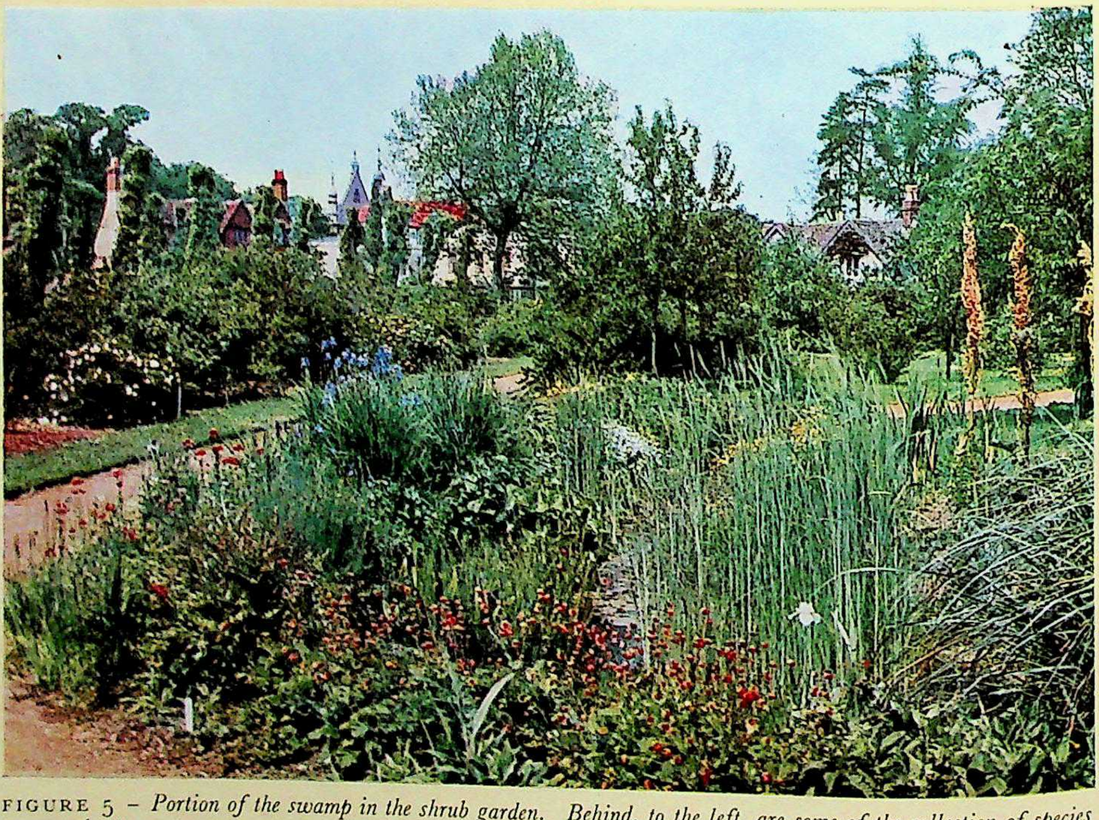

FIGURE 5 – *Portion of the swamp in the shrub garden. Behind, to the left, are some of the collection of species roses and cotoneasters.*

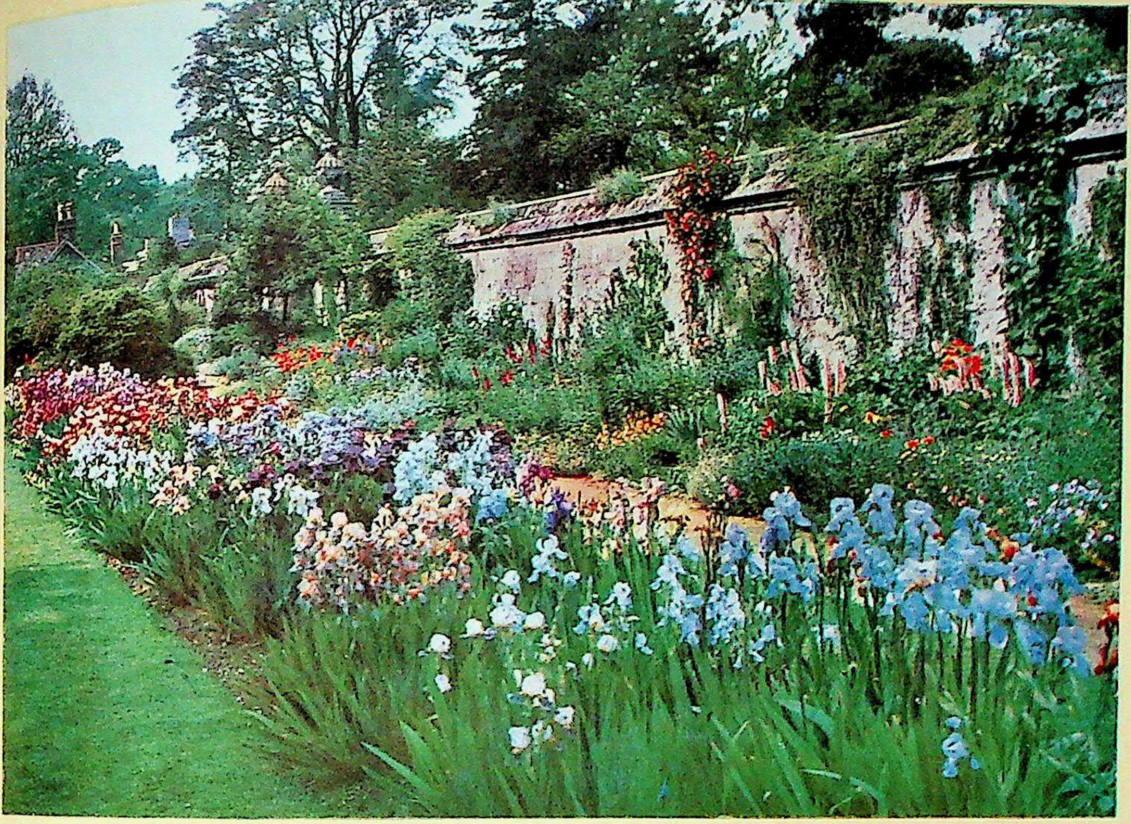

FIGURE 6 – *The south-eastern wall from outside the Garden, showing the hybrid irises and, beyond the path, a mixed herbaceous border.*

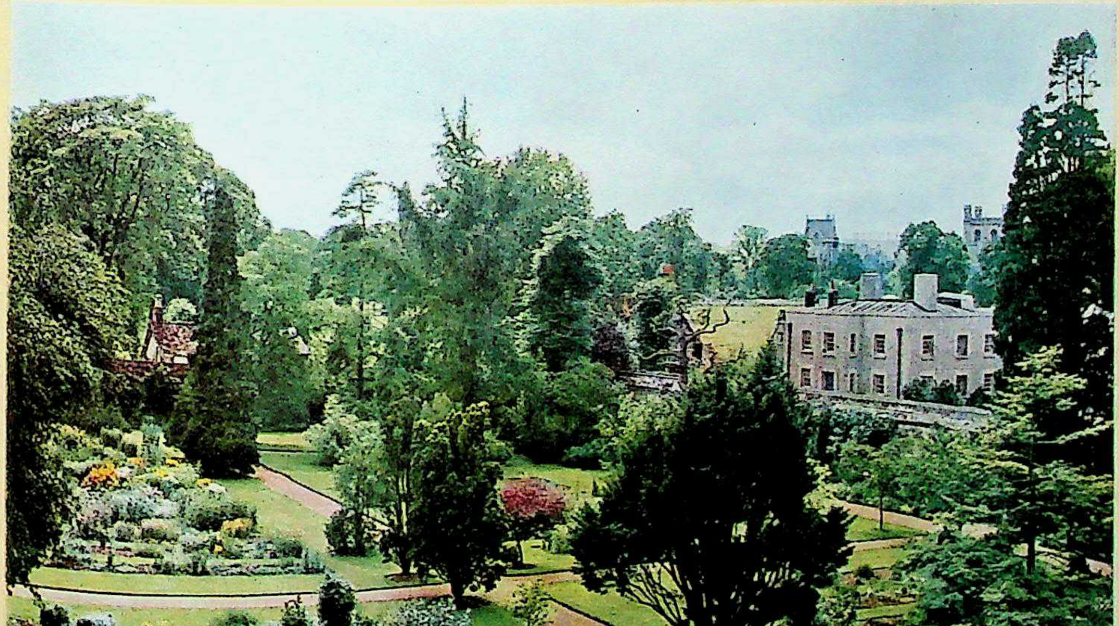

FIGURE 7 – *View of the western portion of the walled Garden, showing the rectangular Order Beds. The large Ginkgo biloba is seen left of centre. Outside to the right is part of Merton College New Buildings, with Christ Church beyond.*

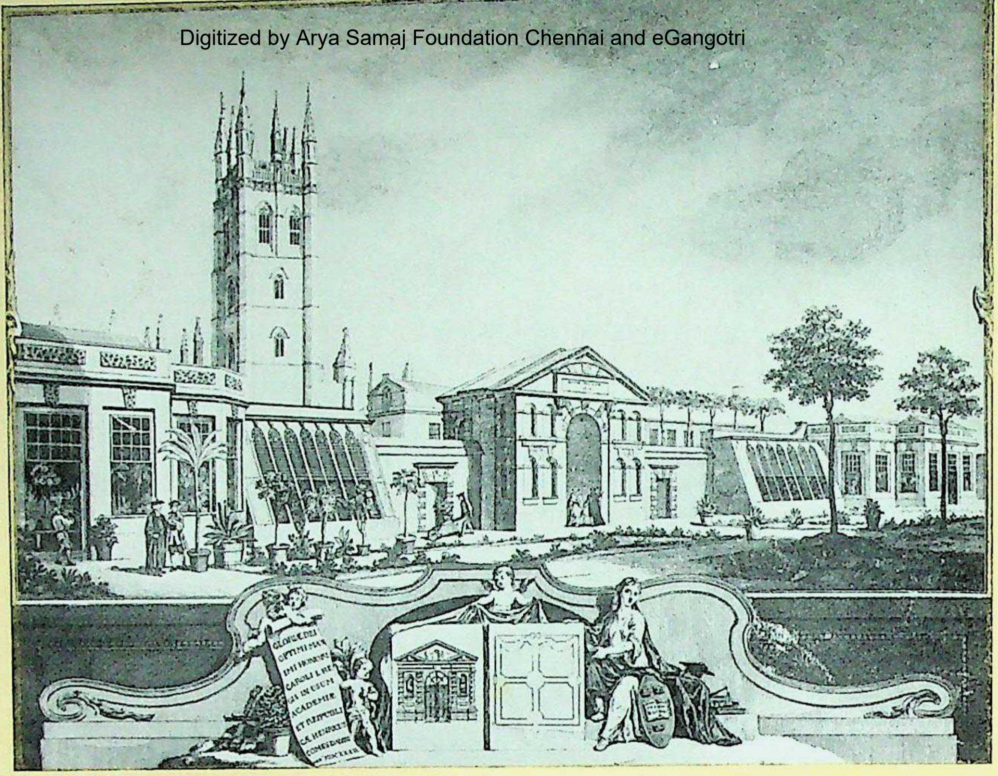

FIGURE 8 – *The range of greenhouses flanking the Danby Gate, from a print of* 1773. *The large range of buildings behind the Danby Gate formed the professor's house and library. The greenhouse on the extreme right is the present library (figure* 2).

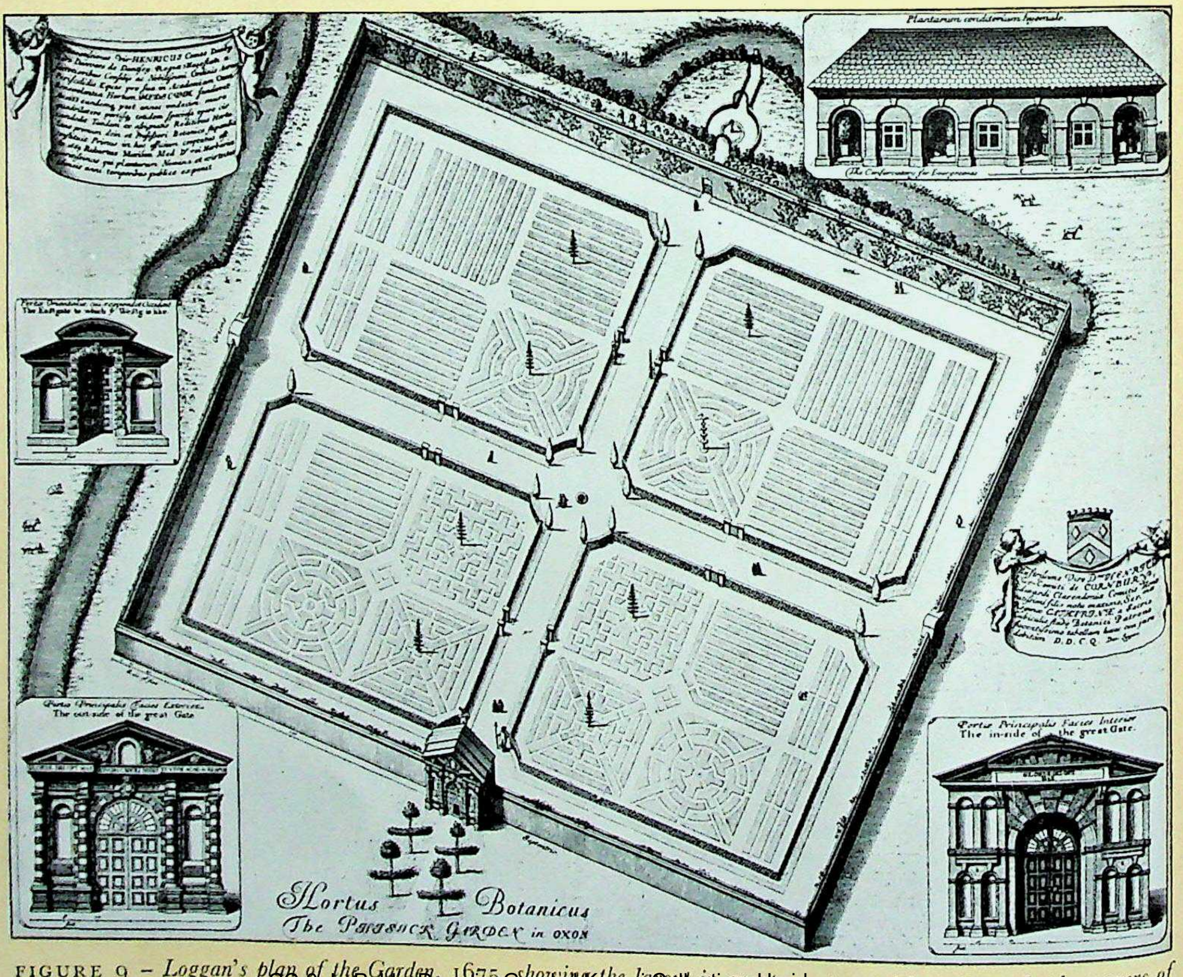
Plantarum conditorium hyemale.
The Conservatory for Evergreenes
The Eastgate
Porta Principalis Facies Exterior.
The out-side of the great Gate
Porta Principalis Facies Interior
The in-side of the great Gate.
Hortus Botanicus
The Physick Garden in Oxon

FIGURE 9 – *Loggan's plan of the Garden,* 1675, *showing the layout in quarters separated by hedges. In the corners of the plan are elevations of the gateways and (top right) the conservatory.*

records that among other things he was shown the sensitive plant *Mimosa pudica*, which also impressed Celia Fiennes on her visit some thirty years later. She records it as being a 'nice plant' and kept under glass, the air being too rough.

The first greenhouse, which was of the room or orangery type, was built outside the wall backing on to High Street, as Loggan's plan shows. It must have been very inadequate, and early in the eighteenth century the range of plant houses shown in a print of 1773 was erected (figure 8). They are referred to in a letter to Dr Richardson dated 11th July, 1734, as being built. The two greenhouses of orangery type still exist. One, in its unaltered shape, is the library (figure 2); the other has been incorporated into the laboratories (figure 1), but the piers of the doorway and two flanking windows are clearly visible in stone older than is used in the remainder of the building.

Among the manuscripts in the library is part of a notebook, probably in the handwriting of Humphrey Sibthorp, the second Sherardian professor, which gives a catalogue of the plants growing in the Garden, then evidently still divided into quarters. The last entry, which helps to date the book, is a note that a vine from Virginia had been planted in 1770. There is no evidence that any of these actual plants survive today, but it is interesting to note that some of the wall plants located in this old list have modern representatives growing in approximately the same positions, notably the honeysuckles (*Lonicera*) grown on the north face of the southern wall.

Before the close of the eighteenth century there was a drastic rearrangement, and the old traditional quarters disappeared. Arboreta, with a geographical grouping of the trees, were planted on both sides of the main north–south path, and by the eastern and western walls. It is possible that some of these trees survive: there is certainly a suggestive grouping of British, European, North American, and Asiatic trees beside these paths today. The space between the rows of trees was laid out in long rectangular beds in which the plants were arranged according to the Linnean system. During the Victorian period these were replaced by various rounded and curved beds distributed over lawns, but the Linnean system was continued over the greater part of the area. Finally, in 1886, the present layout, with rows of beds planted with herbaceous species grouped in families arranged according to Bentham and Hooker's Natural System, was adopted. Apart from its convenience to botanical students, the regularity of these beds is in keeping with the formality of the walled Garden (figure 7). The systematical grouping is broken in front of the buildings (figure 1), and round the walls, where there is a mixture of herbaceous perennials backed by shrubs and climbing plants, placed with due regard to their need for direct sunshine or protection. A sufficient number of trees and shrubs has been left to break what would otherwise be an open expanse.

Of the trees growing within the Oxford Garden the most noteworthy is a huge specimen of *Sophora japonica*, planted about 1817 and now almost 17 ft in girth at breast height. Also remarkable is a magnificent specimen of the service tree (*Sorbus domestica*), traditionally a descendant of the famous specimen in Wyre Forest, brought to the Garden by John Sibthorp (Professor 1784–96). The tree is certainly an old one—it is 6 ft 10 in. in girth—and from its position in relation to the paths it must have been planted long before the existing layout. Its leaves, which turn a brilliant red in the autumn, are seen in the foreground of figure 2. The ginkgo is also a large one for Britain, being 7 ft 5 in. in girth. It is quite possible that this tree also dates from the late eighteenth-century plantings; it is on the Asiatic side, and Daubeny in his guide of 1853 refers to it as among the older trees.

The modern range of greenhouses dates from the last century, but the structures have been recently renewed. They are outside the walled garden, with a south-eastern aspect facing the River Cherwell. There are nine houses in all, of which seven are open to the public. A representative selection of plants is maintained, but the houses are too small to allow of any spectacular display or great specialization. The succulent collection is good, but it is no longer possible to claim—as was done in 1876—that it is second to none in Britain. Outstanding among the collections is the large tank for tropical water-lilies. Originally built for the culture of the *Victoria regia*, this was soon given up and replaced by a mixed collection of hothouse aquatics. The tank is banked by a long swamp in which, among other things, are large clumps of papyrus and sugar cane, descendants of plants which have been cultivated in this position for the last century (figure 3).

Within the last five years, the Garden has extended to the south, allowing of the development of a shrub garden. Previously, the shrubs had been crowded into shrubberies within the wall. The new ground permits the cultivation of a more extended range, which can be grouped in related genera, while the individual plants have room to spread, so that they flower more freely. The collection of *Berberis*, though necessarily small, has been carefully selected with the aid of the Rev. Dr Ahrendt, an authority on the genus. A collection of species rose is being built up, and a number of old-fashioned roses now passing out of cultivation are preserved. Unfortunately, the heavy calcareous nature of the soil prevents any attempt to cultivate a great many popular and beautiful genera of lime-intolerant plants.

The rock garden is small, but contains a surprising number of species. Though at its best in the early part of the year, it is seldom without some object of interest to the student and to the rock garden enthusiast, though here again the growth of calcifuge species is precluded because of the limy soil and water supply.

The mass cultivation of popular species in all their range of horticultural varieties is neither possible nor desirable in a small scientific garden. An exception is made with regard to irises and roses. As can be seen from figures 4 and 6, the irises make a brave show in May and early June, soon to be followed by the roses throughout the remainder of the summer. Of late years, it has been the policy of the curators to grow groups of the more recent roses, so that visitors may judge their performance under local conditions.

It is only to be expected that, during its long history, many names famous in botany and horticulture should be associated with the Garden. The first *Horti Custos*, Jacob Bobart, Senior, was a well-known Oxford character in his day. He wore a great beard which he 'tagged with silver' on feast days, and was renowned for his topiary work, notably for two giants formed from clipped yews which, standing just inside the Danby gate on either side of the main path, appeared as guardians of the treasures beyond. Their position is indicated on Loggan's plan (figure 9).

Bobart's son was gardener when Robert Morison, appointed by Charles II in 1669 as first professor of botany in Oxford, died in 1683. Morison was engaged on a great work, *Plantarum Historiae Universalis Oxoniensis*, of which only volume II had appeared when he died. Bobart completed volume III from the material that Morison left, but volume I was never written. Bobart is mentioned several times in the works of John Ray, and is memorable because of certain observations which he made upon the possible occurrence of sexual reproduction in plants, then not recognized. Had he published these observations at that time he might have gone some way towards anticipating the work of Camararius (1694). He held office until 1719, when he was retired in his seventy-ninth year and died shortly after.

The state of neglect into which the Garden had fallen early in the eighteenth century as a result of Bobart's old age, lack of money, and little interest on the part of the two professors who succeeded Morison (we know little of them but their names), led indirectly to a vigorous revival.

William Sherard, whose interest in botany may well owe something to Morison, for he was elected to a fellowship at St John's in the year Morison died, finally returned to live in England in 1721, after many years as Consul at Smyrna. He had collected a large herbarium and a remarkably fine library, which, together with an endowment for the chair of botany, he offered to the university if, for its part, the university would have the Garden put in order, erect proper greenhouses, and provide a regular income for maintenance. Sherard also stipulated that his botanical assistant, J. J. Dillenius, one of the foremost botanists of the day, should be the first Sherardian professor. Sherard died in 1728, and the protracted negotiations between his executors and the university afford an interesting sidelight upon early eighteenth century Oxford. In the end, Dillenius was appointed to the chair in 1734, and the university contracted to provide £150 per annum for the upkeep of the Garden. The financial arrangements were put into the hands of a committee, who drew up rules for the guidance of the professor and of the gardener. The latter was appointed by the committee, who renewed the appointment annually, a condition being that the gardener took an oath of obedience to the professor. The early minute-books show that the committee's work was not more onerous than an annual meeting, at which the accounts were received and the gardener's re-appointment was considered. The accounts for 1734 show that almost £2700 had been spent on the Garden in the previous four years.

It was early in Dillenius' tenure of the chair that Linnaeus visited the Garden. Writing to Richardson, 25th August 1736, Dillenius adds as a postscript 'A new botanist is arose in the north; a founder of a new method *a staminibus et pistillis*, whose name is Linnaeus . . . am afraid his method won't hold.' This reference, written some months after the visit, suggests that the older man still felt somewhat unkindly disposed towards the young Swede. It is said that Linnaeus' brilliant diagnosis of the little ivy-leaved toadflax (*Linaria cymbalaria*) which still grows freely on the Garden wall, first showed Dillenius that his visitor could do more than 'bring confusion into Botany.' It is certain that Linnaeus was able to return to Holland with many plants and cuttings from the Oxford Garden desired by his patron, Clifford, which he had been unsuccessful in obtaining from the Physic Garden at Chelsea. Dillenius' letters show that he sent packets of seed to Linnaeus, on one occasion as many as 140 at one time. Dillenius was succeeded by Dr Humphrey Sibthorp, of whom it is recorded that he gave one unsuccessful lecture in the course of the 37 years that he was professor. The Garden minutes record a series of appointments of gardeners notable only for the name of G. D. Ehret, the celebrated painter of flowers. He was appointed in November 1750 at a salary of £50 per annum, with perquisites, but had to find the necessary labour. The following year he was re-appointed, but as he then refused to take the oath of obedience to the professor, the election was declared void. No doubt it is true that he had 'more ardour than the Professor' but the committee could hardly do otherwise than dismiss him.

Throughout the latter half of the eighteenth century and well into the nineteenth, the duties of the chair and the affairs of the Garden were closely interwoven. It is highly probable that the rearrangement of the Garden and the introduction of the Linnean system occurred during the professorship of the younger (John) Sibthorp (1784–96). Much of Sibthorp's tenure of office was spent by him in travels in Greece, collecting material for his great *Flora Graeca*. It is difficult to guess what might have been his influence upon the Garden had he lived longer. As he was founder of the Sibthorpian chair of rural economy it is possible that development with attention to experimental work might have taken place. In the event, after 1790, there was no meeting of the Garden committee for 22 years. Sibthorp was succeeded as professor by Dr George Williams, who combined the duties of a practising physician with those of Sherardian professor. Though an elegant scholar, his practical experience of plants does not seem to have been great. As Sir James Smith, a founder of the Linnean Society, said, 'Botany at Oxford slept.' But a change was coming. It was heralded by the appointment in 1813 of William Baxter as gardener at £50 per annum, and so began an association with the Garden that lasted 58 years. At first Baxter could do little in the Garden for want of money and backing. The greenhouses, nearly 80 years old, were falling to bits. Their heating arrangements were primitive. An open brazier with glowing coals was wheeled on a trolley round the orangeries in cold weather, and the flood menace was severe. Baxter built up an extensive collection of willows, and devoted much attention to non-flowering plants. It was when the horticultural skill of Baxter was aided by the drive and enthusiasm of Professor Daubeny that the Garden had its second revival, so that by the middle of the century it was regarded as the most remarkable scientific garden in Britain.

C. G. B. Daubeny was educated at Winchester and at Magdalen, where he became fellow in 1815, later proceeding to Edinburgh to study medicine. He returned to Oxford in 1822 as Aldrichian professor of chemistry. He was best known for his work on volcanoes, but as he had published on such diverse botanical subjects as the mineral nutrition of plants, their irritability, and their metamorphoses, he was elected Sherardian professor in February 1834 on the death of Williams. Legend has it that on the very night of his election he was seen in the Garden with Baxter planning its rearrangement by the light of a lantern. Daubeny begged money from his friends and his college, contributed largely himself, and speedily began a reformation. The erection of more modern greenhouses was one of his first actions. He also built a residence for the professor, in part an upper storey to the old orangery (figure 2). In 1840 he became Sibthorpian professor of rural economy, and so for a time held three Oxford chairs simultaneously.

In Daubeny's time the study of botany with organized classes and laboratory instruction did not exist. It was begun in Oxford under his successor, and a science department in the modern sense has developed. When, some 80 years ago, the university was building its science laboratories in the Parks, there was a plan to give up the old Garden and transfer all the university's botanical interests to the Parks, where a new and larger botanic garden would have been possible. The suggestion was hotly debated, but in the end the scheme was abandoned. Although in a short time the department of botany will be transferred to new laboratories in the science area, it is to be hoped that the ancient Physic Garden will long continue to serve the university and the state within its original walls.

Radioactive phosphorus and exchange of lake nutrients

F. R. HAYES and C. C. COFFIN

Information about the fate of phosphorus added to lake water is of particular importance because of the evidence that in lakes the addition of this single element can greatly stimulate production. The results obtained by the authors on the ultimate movement of radioactive phosphorus added to a small lake indicate that ionic distribution occurs many times more quickly than had been supposed, and that depositions and removals take place by exchange.

INTRODUCTION

If one contemplates the improvement of agricultural lands by addition of fertilizers, the elements which come first into consideration are nitrogen, potassium, and phosphorus. It was natural that, in the first attempts to improve the fertility of waters, attention was directed to these substances. There is, however, some evidence (Neess, 1946) that phosphorus by itself can stimulate production in lakes quite as well as mixed fertilizer does. This may be because potassium is present in sufficient quantities, and the availability of nitrogen is stimulated when phosphorus is added (Einsele, 1941).

Experiments on the addition of phosphorus to lakes have, in general, shown that the extra material rapidly and almost completely disappears from the water (Smith, 1945; Orr, 1947). When ordinary phosphate fertilizer is used, the amounts added have often been quite large—up to 10 or 100 times the amount originally found in the water, the latter being of the order of 25 parts per 1,000,000,000, of which nine-tenths is organic. As the remarks to follow will show, the same rapid disappearance is observed even when the amount of added phosphorus is only 1 or 2 per cent. of the quantity already in solution, as in experiments with radioactive phosphorus. The mechanism by which such rapid removal takes place obviously deserves study.

THE PHOSPHORUS-IRON CYCLE

It may be worth while at this point to mention briefly some conclusions reached by Einsele (1936) and Mortimer (1941–2) regarding the mechanism of nutrient exchange. A lake in spring may be considered to have its water saturated with oxygen, and to have a layer of oxidized mud about 1 cm thick at the bottom. In this oxidized layer there will be insoluble ferric phosphate, while in the deeper layers of the mud there will be soluble ferrous phosphate. The oxidized layer of mud provides a barrier which prevents the phosphorus from reaching the water. As the summer wears on, oxygen becomes depleted in the lower layers of the lake water, which are cold and relatively stagnant. The iron at the mud-water interface becomes reduced to the soluble ferrous state, permitting solution of the phosphate. Thus the ferrous and phosphate ions move upward until, reaching the higher concentration of oxygen at the thermocline, they tend again to be oxidized and precipitated. One possibility under which some phosphate may penetrate to the surface layers occurs by reason of the presence of hydrogen sulphide in the mud. This compound, formed under certain anaerobic conditions, will precipitate the iron and permit the phosphate to reach the surface layers of the lake. (See figure 3.) So much having been learned without the use of radioactive materials, it seemed likely that the tracer technique might provide further information on the movements of phosphorus in lake waters, and on the nutrient cycle generally.

PRACTICAL CONSIDERATIONS

In any country, some of the lakes will be geologically primitive and relatively infertile; such lakes are often found in quartzite and granite areas. Another type of lake is essentially acid-bog in nature, often surrounded by sphagnum, and usually in non-agricultural areas. A third type is the advanced or meadow lake with reedy margins, frequently associated with farming communities. Experiments involving radioactive tracers are likely to be limited to the first two kinds of lakes, for, owing to the health hazards involved, authorities dealing with the distribution of radioactive isotopes are not disposed to grant

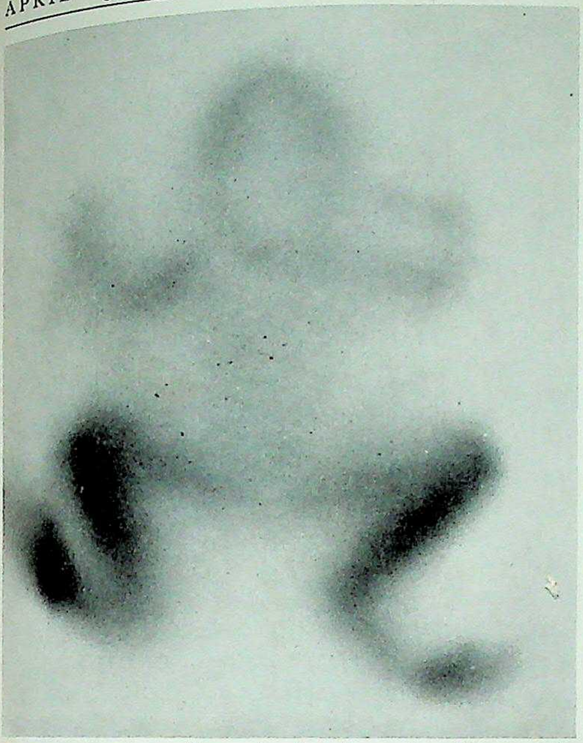

FIGURE 1 – *Autoradiograph of a frog taken from a lake, 40 days after addition of P^{32}. The concentration of tracer in the skeleton is evident. Exposure fifteen days, on dental X-ray plate.*

permission to add such material to waters in a farming community.

Other factors influencing both the type of lake and the element studied will be the rate of decay and the availability of the isotope. Thus it is easier to obtain permission to use relatively large quantities of P^{32} (half-life about 2 weeks) than C^{14} (half-life 5000 years).

EXPERIMENTAL

The first lake experiment with P^{32} was made by Hutchinson and Bowen (1947), who added 10 millicuries to a stratified 14-acre lake in Connecticut, U.S.A. Their results showed mixing in the epilimnion, and they inferred that there was penetration into the hypolimnion. They also record a 1000-fold concentration of material in the tissues of such littoral plants as *Potamogeton* within a period of one week.

In our experiments with lakes, three additions of radioactive phosphorus have been made; they will be described in turn. The first experiment involved the addition of 100 millicuries of P^{32} to a highly stratified acid-bog lake less than an acre in area, and with a maximum depth of 22 feet (Coffin *et al.*, 1949). Samples of aquatic organisms were removed for analysis at intervals, beginning two hours after the addition of P^{32}. There was a rapid and immediate uptake by zooplankton, sponges, sphagnum, and algae, suggesting that these forms may be able to deal with inorganic phosphorus directly. Rooted plants, such as cranberry and leather leaf, did not show significant activity until two weeks after the experiment began. Fishes, such as *Fundulus* (of which 4000 were added to the lake before the experiment began), and *Notemigonus*, failed to show any measurable activity until several days had elapsed. This suggests that such forms obtain their phosphorus indirectly by feeding on plankton. The distribution of the activity through the organisms was studied by autoradiographs, as illustrated in figure 1, which is a self-photograph of a frog. Systematic sampling of the lake water showed a rapid decrease in the total activity present, 90 per cent. having disappeared within one month. There was no evidence at any time that the added phosphorus reached the deepest waters, although some penetration of the thermocline was observed.

In the second experiment, which was carried out in 1949 and has not yet been published in detail, 100 millicuries of P^{32} were added 3 feet

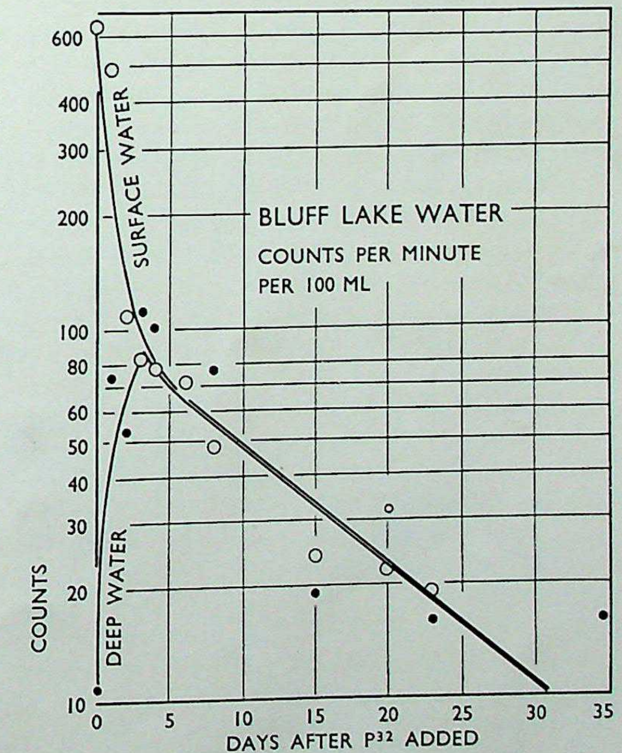

FIGURE 2 – *Concentrations of radio-phosphorus in surface water and deep waters of a lake in which complete mixing occurred. Time is measured from the deposition of P^{32} at the surface. The ordinate is logarithmic.*

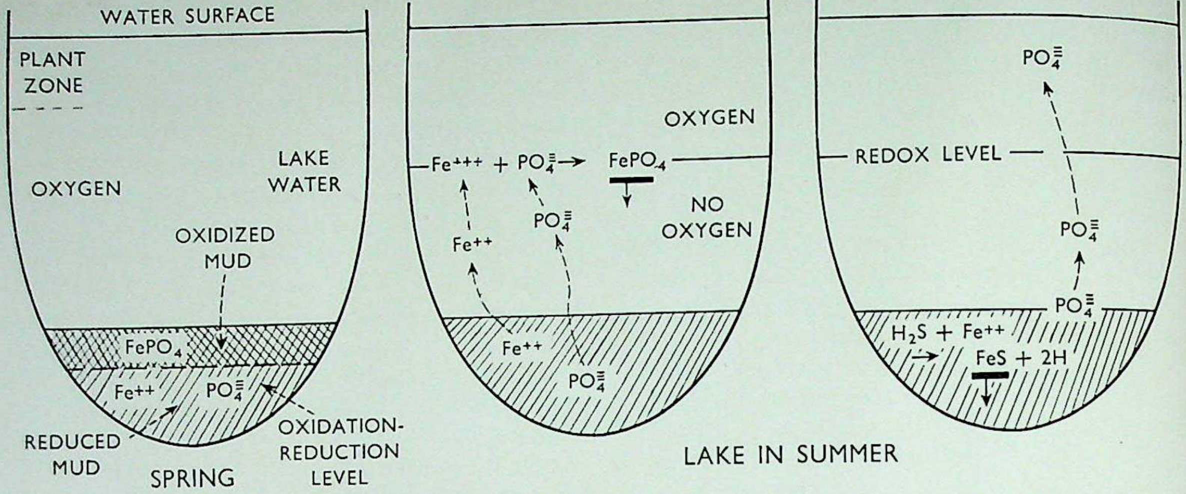

FIGURE 3 – *Exchanges between lake mud and water in spring and summer.*

above the bottom of the same lake. The material was placed in a large bottle filled with water, and after temperature equilibration the bottle was exploded from the inside with a dynamite cap. Samples were taken at intervals over a period of three months. It was found that the radioactive phosphate moved through the cold layer of water at the bottom of the lake very slowly, the maximum speed observed being approximately five feet per hour in a lateral direction. The movement in the hypolimnion was laminar; thus within two months the added material moved 160 feet in a horizontal direction until it reached the shore, but it did not move in measurable concentrations more than 12 feet vertically upwards.

It was known, as a result of our first experiment, that certain plants have the ability to concentrate phosphorus up to 40,000 times the concentration in the surrounding water. Accordingly, biological samples were taken from the surface waters and analysed for P^{32}. It was found that specimens taken from locations where no radioactive phosphorus could be detected in the water did in fact contain radioactive phosphorus in their tissues. The explanation offered is that these forms are able to extract phosphorus from a larger volume of water than it was possible for us to collect and analyse. The concentration of radioactive phosphorus in the mud reached very high values, indicating that most of the active material added to the lake was removed by the mud.

For the final experiment to be reported, a lake of about eight acres in area and twenty-five feet in depth was selected, of a type providing a complete contrast to the first one. It is a primitive lake, with little vegetation and no sphagnum, and is completely mixed from top to bottom, so that gradients of oxygen and temperature are not observed at any time. One thousand millicuries of P^{32} were added at the surface, and analyses made at intervals as shown in figure 2, from which it is seen that surface and bottom waters reached equality of concentration within a few days; after that, there was a steady decline. It will be observed that figure 2 has been plotted in a semi-logarithmic manner, suggesting that the removal of P^{32} is more rapid at the start than later on. A remarkable feature of the experiment, which confirms previous observation, was the very rapid disappearance of the activity. This is difficult to understand, because the enhancement of phosphorus in the lake amounted to only about 0·25 per cent. We have been greatly puzzled as to why the added material should appear to be selectively removed. The probable interpretation is that we are not dealing with removal as such, but with an exchange phenomenon in which there is a rapid equilibration between the mud, plants, etc., on the one hand and the water on the other. If, for instance, the mud and living forms contained 1000 times as much phosphorus as the water, and if equilibration between them were rapid, any added material would soon become distributed in the ratio of 1000 parts in the mud to one part in the water. If one were measuring water only, this would be regarded as a great and rapid loss of material. The slope of the line in figure 2 indicates that some 7 per cent. of the P^{32} is removed each day, which points to a complete turnover of phosphorus in the water every fortnight. Naturally, one particular atom might exchange several times, another not at all.

An understanding of how exchange of ions might be confused with their apparent removal may be illustrated by consideration of money transfers. Suppose that most of the money in a town at any given moment is in the banks. Suppose further that one dispersed a supply of marked banknotes at random through the town. Within a few days, it would be found that under normal processes of commerce most of the marked notes had moved into the banks. This would not mean that the banks were specifically removing marked notes from circulation, or that the ratio of money in the bank to money outside had changed. It would merely be proof that the banks were engaged in active trading, which is the important consideration in the present case.

CONCLUSION

Experiments of the type described, on biological systems generally, have led to two conclusions, the first one being that ionic distributions take place at a rate from ten times to one hundred times greater than had previously been supposed. The second is that depositions and removals of material do not take place separately, but that one should think rather of exchanges. It appears likely that results of the application of tracers to limnological investigations will offer further support to such concepts.

It is a pleasure to acknowledge the support given to our work by the Nova Scotia Department of Trade and Industry, the National Research Council of Canada, and the Nova Scotia Research Foundation.

NOTE ON PHOSPHORUS 32

Phosphorus 32 has a half-life of 14·3 days. It emits only beta radiation, of a maximum energy of 1·7 million electron volts. These beta rays are quite energetic and easily measurable.

The material can be prepared by the action of neutrons on ordinary phosphorus of atomic weight 31, in which case the specific activity, or activity per gram, of the final material is limited, because the product and the target material are identical chemically. It is usual to irradiate red phosphorus in the atomic pile and to dissolve the irradiated material in moderately strong nitric acid, when orthophosphoric acid is obtained labelled with phosphorus 32 at a specific activity of about 10 millicuries per gram.

If phosphorus 32 is required at higher specific activity it has to be made by the (n, p) process on sulphur 32. In this process ordinary elementary sulphur is irradiated in the pile, and some of the sulphur 32 atoms absorb a neutron, emit a proton, and are converted to phosphorus 32. Because the product nucleus differs chemically from the target nucleus it is possible to extract the phosphorus 32 from the sulphur without having a large amount of inactive phosphorus present. This is usually done by melting the sulphur and extracting with nitric acid. Either concentrated acid is used at atmospheric pressure, or dilute acid in a pressure vessel. The phosphorus appears in the aqueous phase as orthophosphoric acid, and can be separated from the other materials present and prepared at very high specific activity. Phosphorus 32 intended for tracer experiments is almost always prepared by the second of these two methods.

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The Science Museum, London

F. SHERWOOD TAYLOR

The Science Museum, London, is one of the most comprehensive of its kind. In the present article the Director, Dr Sherwood Taylor, has not attempted to be lyrical about its treasures and merits, but has given a plain and simple factual account of its chief contents, its organization, and its planned extensions. This account will, it is hoped, be of assistance and value to all those interested in the historical aspect of science, whether in Britain or overseas.

The Science Museum, London, which is the British national museum of science and industry, came into being as a result of the great Exhibition of 1851. The Prince Consort's proposals for the furtherance of industrial education, and the extension of the influence of science and art upon productive industry, led in 1853 to the formation of the Department of Science and Art, an essential part of whose function was to form a museum of science and art. Collections illustrating these subjects already existed at Marlborough House, but were transferred in 1856 to a large corrugated iron building on the site now occupied by the Victoria and Albert Museum. This building was opened in 1857 as the South Kensington Museum. These premises, which from their mode of construction acquired the not inept nickname of the Brompton Boilers, were soon outgrown, new buildings were erected on the same site, and the science collections were later transferred to other buildings on and near the present site of the Science Museum. The science collections were much augmented, especially by the transfer of the Patent Museum in 1883. The most important event in the Museum's history, however, was the separation of the art collections in 1909 to form the Victoria and Albert Museum, and the assumption of the status of a separate institution by the science collections, under the title of the Science Museum. The galleries available were both crowded and inadequate, so for this and other reasons a committee under Sir Hugh Bell was appointed in 1910 to inquire into the organization, aims, and requirements of the Science Museum. As a result of its recommendations, there was begun a series of buildings which even yet is not completed. The eastern block, familiar to all Londoners, was opened in 1928: this is being supplemented by a central block, now in process of construction. A western block is contemplated in due time.

The objects of the Museum are to illustrate and explain the various branches of science, and their application in the arts and industries, and to afford a worthy and suitable house for the preservation of appliances which hold honoured place in the progress of science or the history of invention. Medicine and biology (except as far as it enters into agricultural technique), and likewise geology, have been excluded from the scope of the Science Museum, as being represented in other national museums, but the whole of the rest of science, pure and applied, lies within its field. The provision of information has likewise been one of the Museum's functions, and the Science Library, which is one of its departments, is one of the chief scientific libraries of Great Britain.

The Science Museum has a larger number of visitors than any other in Great Britain; these range from multitudinous small boys and girls to historians of science and expert engineers, a fact which sets difficult problems in the display of exhibits. Its primary duty is to the general public rather than the expert, and great efforts are therefore made to illustrate the simplest principles of its subjects in the clearest possible manner—especially by working models, which have an intense fascination for the young scientist and engineer. This primary regard for the general public has made the Museum reluctant to form what may be called 'collectors' collections,' exhaustive of their subject: unlike the majority of the museums it displayed in pre-war days 95 per cent. of its total material, and refrained from forming considerable reserve collections for the use of students.

The collections, other than of books, are divided into seven departments: physics, chemistry and photography, land and water transport, mining and electrical engineering, aeronautics and sailing ships, motive power and industries, and astronomy and geophysics.

The present department of physics has for its scope the well-known branches of physics—heat, sound, optics, electricity and magnetism, with the more modern developments of electron physics and atomic physics. Time measurement, a science based on physical laws, is also included, as are two special historical collections, the H.M. King George III collection and the Rayleigh collection. The H.M. King George III collection consists of a collection of very beautiful scientific apparatus, assembled under the patronage of that monarch and used for the education of the royal children; the small Rayleigh collection consists of home-made apparatus used by the third Lord Rayleigh, and illustrates the versatility of his genius.

The sections relating to the branches of classical physics consist mainly of historical sequences of exhibits showing the development of the various instruments employed in these branches of physics. The collection of microscopes is particularly full, and is probably the most representative in existence. The most remarkable example is perhaps Hooke's microscope, made by Christopher Cock (figure 1), which at one time formed part of the H.M. King George III collection. Occasional explanatory and illustrative exhibits are also included in these sections, and it is intended in the future to increase the number of the exhibits illustrating physical phenomena, as they are educative in themselves and enhance the interest of the more static instrument collections.

The electron physics and atomic physics sections are doing their best to keep pace with these rapidly developing subjects. The range of the time measurement section extends from the water- and shadow-clocks of ancient Egypt to the quartz-crystal clocks of today.

The chemistry collections developed at a later date than those illustrative of physics, and it is only now, with the building of new galleries, that we are able to contemplate the display of industrial chemistry in a worthy manner.

The section on pure chemistry includes many famous exhibits, such as original specimens of Faraday's benzene (1825), Crookes' thallium metal and compounds (1862), Wollaston's rhodium and palladium (1803–4), and the apparatus and spectrum-tubes used by Ramsay and his collaborators in their researches on the rare gases of the atmosphere (1895–8). To the present sections on inorganic and organic chemistry will shortly be added collections illustrative of molecular structure, biochemistry, and analytical chemistry.

The main branches of industrial chemistry have hitherto been illustrated by a series of historical models; that of the nitroglycerine plant shown in figure 4 is a typical example.

Worthy of mention are complete models of an early sulphuric acid chamber plant and of a Leblanc soda works. The first type of retort used by James Young in 1851 for distilling oil from torbanite can be compared with a modern bench of 'Pumpherston' oil shale retorts. The fermentation processes and manufacture of explosives are well represented, and some of the earliest specimens of artificial silks and dyestuffs are preserved in these collections. Nevertheless, the great advances of the British chemical industry are not yet reflected here, and it is intended that a feature of the Museum's new extension shall be an attractive and modern display of its principles, methods, and products.

Metallurgy is illustrated by models of ancient and modern types of furnaces for the extraction of metals, and plant used in refining processes. The collection includes examples of assaying apparatus, and of atomic models illustrating the structure of metals and alloys.

The organization of photography and cinematography as separate collections dates from 1929. About the same time, the Royal Photographic Society allowed the more valuable historical exhibits in its collection to be shown in the Science Museum; the combined collections constitute perhaps the finest record of photographic history in the world. In kinematography are included many of the earliest inventions. Beginning with the early mechanical devices which preceded the cinema proper, the collection includes cameras and projectors built both before and after the production of the first celluloid film in 1889.

The department of astronomy and geophysics illustrates the subject of the astronomical universe, including a study of the oceans and atmosphere of the Earth, and the properties and measurements of the Earth itself as one of the planets of the solar system. The scope is in fact roughly what would have been covered by the title cosmography in the eighteenth century. The sections include astronomy, geophysics, geodesy, surveying, terrestrial magnetism, geography, oceanography, meteorology, and mathematics.

The mathematical section shows the historical development of the calculating machine, and also drawing instruments and geometrical models; Babbage's original calculating engines are preserved here. Historical telescopes made by Sir William Herschel, Lord Rosse, and others are shown in the astronomy gallery, where there are sextants, orreries, globes, astrolabes, and numerous transparencies of celestial photographs. Models show the scale of the universe. It is hoped that when the central block is completed we may be able to include a planetarium, and an observatory with a three-foot reflecting telescope for use by the visitors. The geophysics section shows the instruments and methods used in prospecting for oil and minerals, together with working seismographs used for the recording of earthquakes. The surveying and photogrammetric collection contains a good representation of the actual instruments used in the first principal triangulation of the British Isles. It is proposed to develop the section in that part devoted to aerial surveying, and to introduce more cartographic exhibits to make clear the technique of map-making. The historic development of all types of instruments used in meteorological observations is illustrated; the charts used in weather forecasting are displayed; and a set of transparencies shows the most important cloud types and other atmospheric phenomena. Steps are being taken to form a section showing the early history and modern methods of navigation, both marine and aerial.

The engineering collections occupy the greater part of the Museum and are its especial glory. The visitor is greeted on entering the Museum by the view of the East Hall (figure 2), which is devoted to the development of motive power. The exhibits illustrate man-power, water-power, windmills, steam engines and turbines, and gas and oil engines. The great steam engines of the eighteenth century are deeply impressive: other monuments of engineering history are an original Trevithick steam engine (1803), the first Parsons steam turbine and high-speed generator (1884), and the first Diesel engine made in Great Britain (1897).

The collection of hand and machine tools shows in the limited space available examples of prehistoric stone implements followed by simple hand tools such as the axe, hammer, chisel, and drill. Several of the earliest machine tools are exhibited, including the bow-lathe, the pole-lathe, Maudslay's original screw-cutting lathe, Roberts' early metal-planer, Nasmyth's original model of his first steam-hammer, and a series of machines designed by Brunel for the mass-production of naval pulley-blocks.

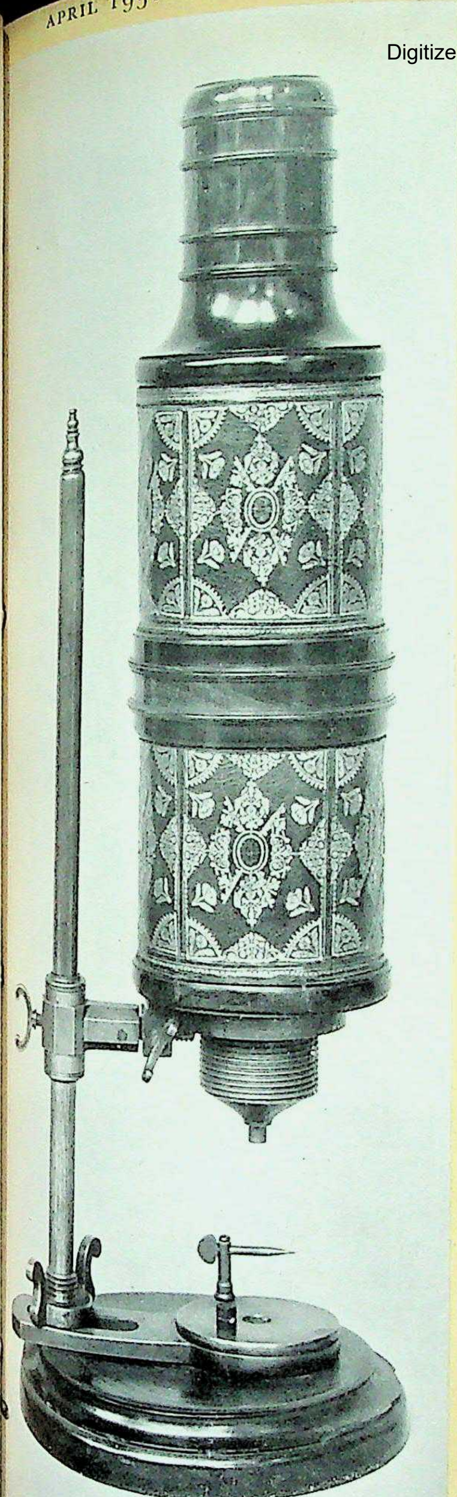
The textile machinery collection naturally starts with the preparation of the raw materials—wool, cotton, flax, silk, and rayon. The development of spinning and weaving is demonstrated by hand spinning-wheels, some original machines used by Arkwright, and replicas of Hargreaves' spinning jenny and Crompton's mule. A ring spinning frame can be worked to show modern practice.

In the weighing and measuring collection, the evolution of the primary standards is displayed in broad period groupings from about 5000 B.C. to the twentieth century. Exhibits of special interest and importance are some ancient Egyptian and Muslim weights and measures from the Petrie collection, the historic Exchequer primary and secondary standards of England from Henry VII to Queen Victoria, with copies of the modern yard and pound standards, a collection of English bronze wool weights, showing the economic importance of the wool trade in England for over 300 years, and the Royal Society linear standards from 1742 onwards, illustrating the beginning of scientific measurement in Great Britain.

An important section of the Museum is concerned with transport of all types. The section on road transport includes many objects of universal appeal, including Sedan chairs and many types of horse-drawn vehicles of the eighteenth and nineteenth century. The development of the bicycle extends from a hobby-horse of 1818 to the most modern types. Motor-cars begin with a Benz three-wheeler of 1888, still in running order; motor-cycles include a Wolfmuller machine of 1884, and the interesting Werner machine of 1899 (figure 3).

The railway collection includes some of the most famous early locomotives, such as *Puffing Billy*, built in 1813, the remains of the *Rocket* and the *Sans Pareil*, and parts of the *Novelty*, the three engines which competed at the decisive Rainhill Trials in 1829, and the first electric Tube locomotive, built in 1890. The development of the steam locomotive is shown by a series of scale models, from a conjectural model of Trevithick's Penydarran engine of 1804 to those of engines now used by British Railways, while various foreign types are represented by a further series of models. Other subjects dealt with include railway carriages and wagons, permanent way, signalling, and tickets. The collection also contains a fine set of early prints and other documents and relics relating to early railways and railway pioneers.

Among the most noteworthy examples in the powered water-transport collection are Symington's and Bell's original marine engines of 1788 and 1812 respectively, the after portion of the *Turbinia* of 1897 including the steam turbines, a small Daimler internal-combustion marine engine



GURE 1 – Hooke's microscope, constructed by ristopher Cock. Originally part of the H.M. King orge III collection.

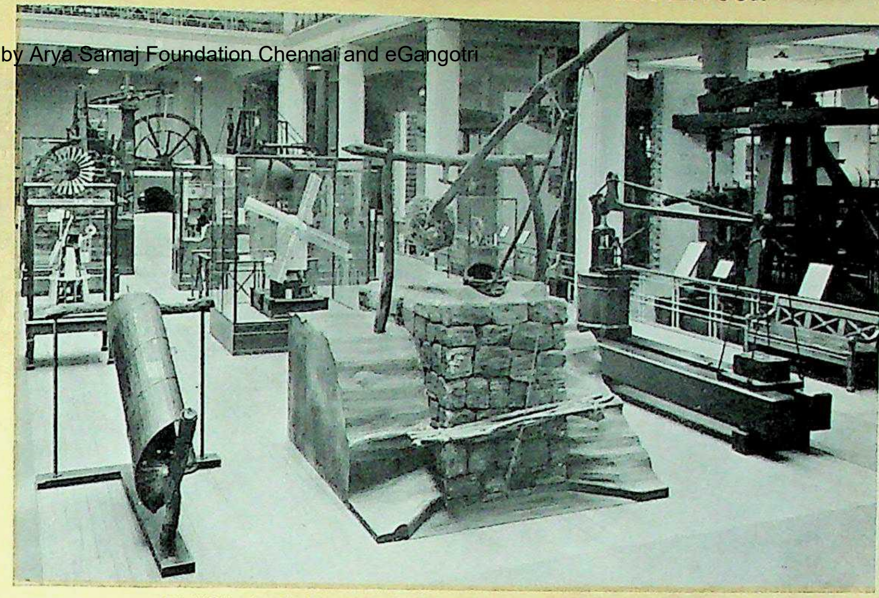


FIGURE 2 – *Exhibits in the East Hall illustrating man-power, water-power, windmills, steam engines and turbines, and gas and oil engines.*

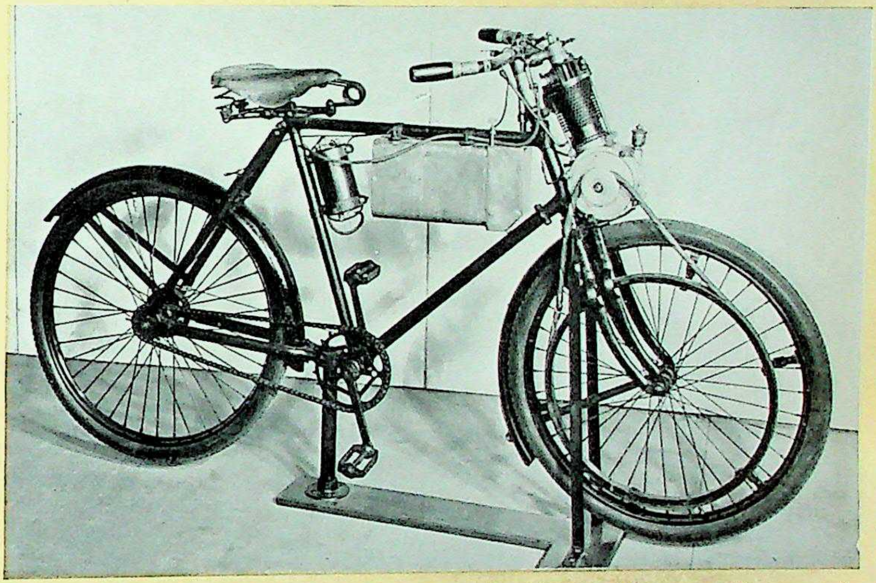


FIGURE 3 – *Werner motor-cycle of* 1899. *There is a striking resemblance to the power-aided bicycles which are once again becoming popular in Britain and elsewhere.*

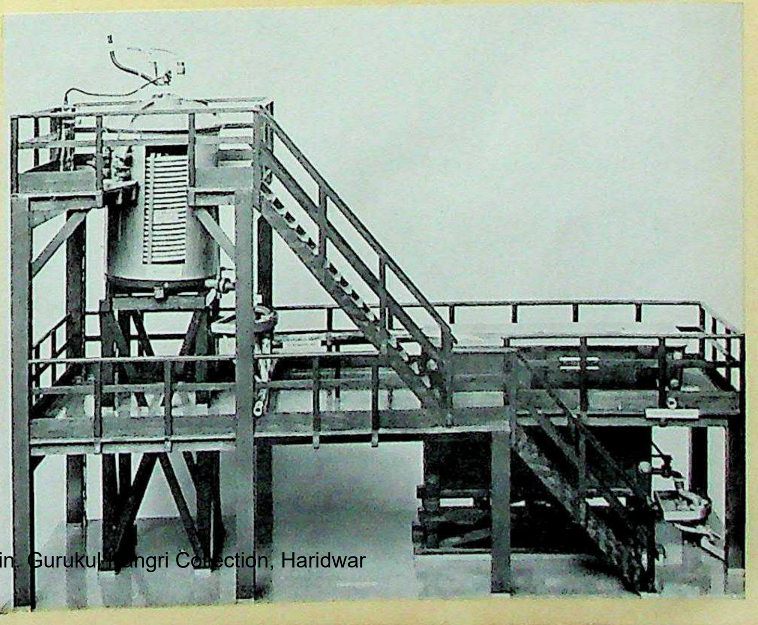


FIGURE 4 – *Model of a nitroglycerine plant.*

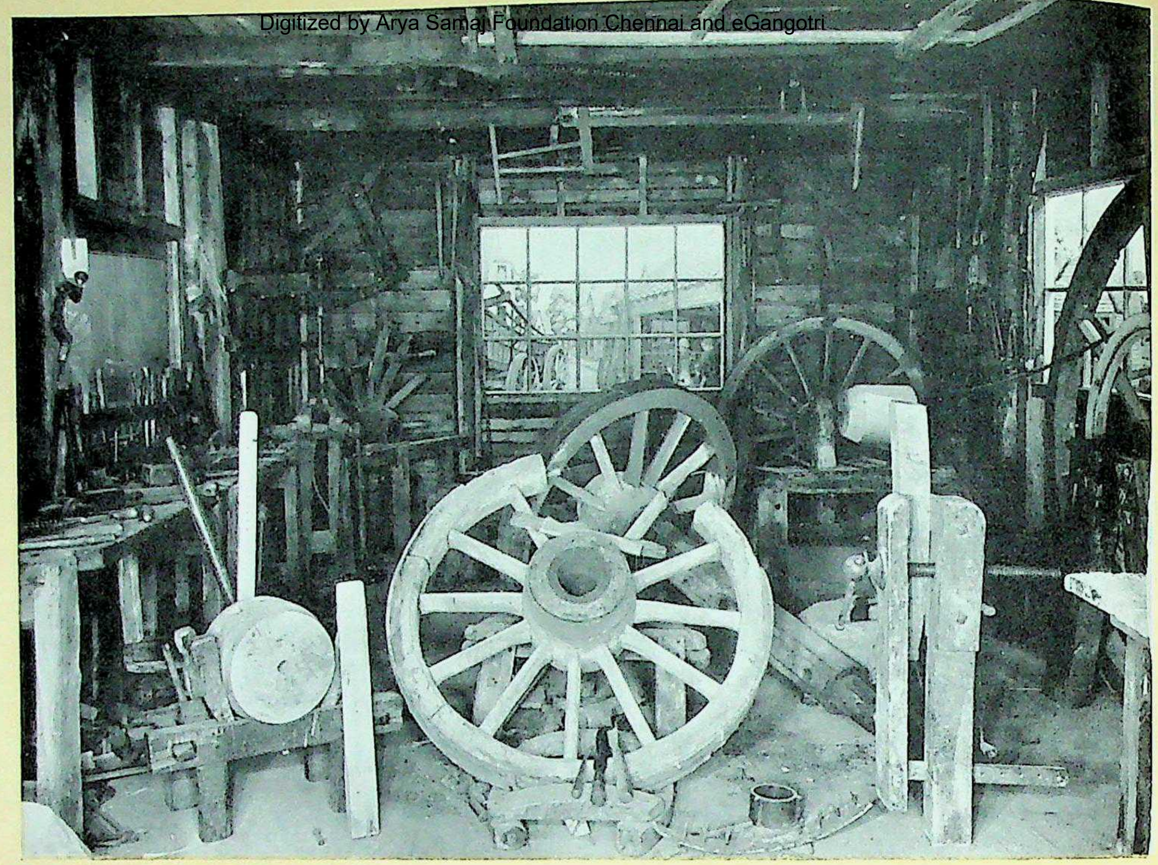


FIGURE 5 – *Model representing an early wheelwright's shop.*

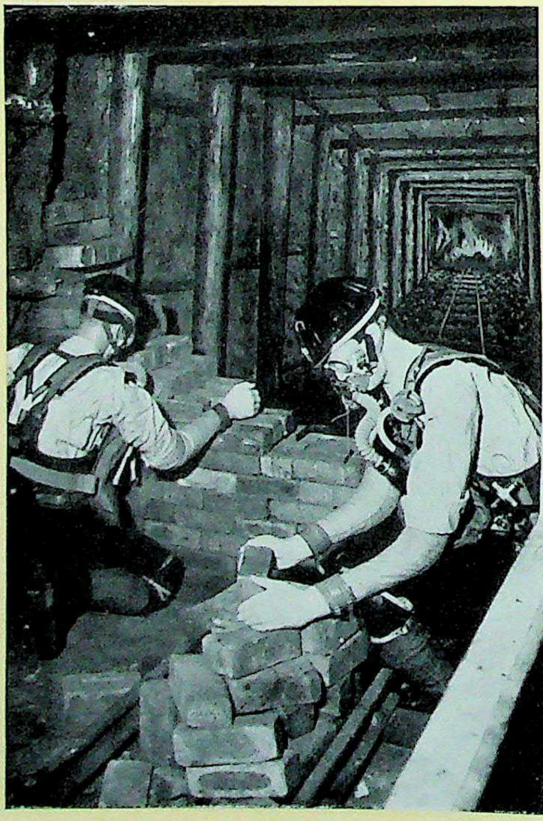


FIGURE 6 – *Model representing a modern coal-mine.*

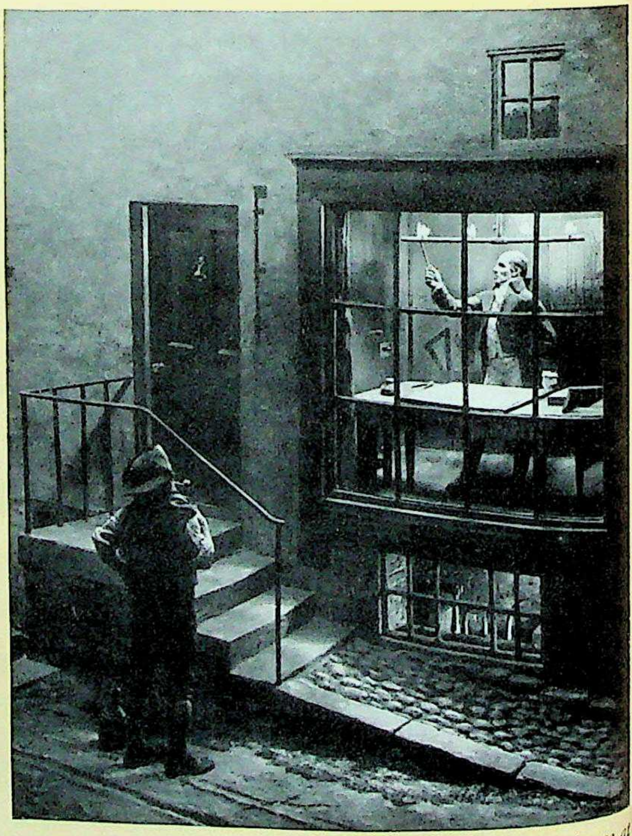


FIGURE 7 – *Model reproduction of William Murdock's house at Redruth with the gas-lighting plant he installed in 1792.*

of 1898, and the gas turbine used in Motor Gun Boat 2009 in 1947. Steamship models form a series covering practically all the important stages of development, while the collection of marine engine models includes many fine examples, such as those of the unique Maudslay collection. The development of paddle wheels and screw propellers, marine boilers, and other accessories is also shown by models and actual examples.

At present, unfortunately, only a proportion of this material can be shown, but with the completion of the central block it is hoped that all the more important objects will once more be displayed.

The aeronautical collection is of comparatively recent origin, but already contains many objects of great historical interest as well as a large number of the most modern types. It is at present shown in premises separate from the Museum, the Western Galleries, but will finally find its home in the new central block. The early models of Stringfellow and Henson, and an original Lilienthal glider (1895), are among the earlier exhibits. The original Wright aeroplane (1903) was exhibited from 1928 to 1948, but has now been returned to the United States and is replaced by a replica. The historic machine in which Alcock and Whitten-Brown first flew the Atlantic is another treasured possession.

The agricultural collections are in a state of rapid development. The Museum has fine historical collections of agricultural tools and machines from the most primitive times. These are being augmented by a striking display of modern farming machinery and methods, which will be displayed to the public this year.

Another very successful display has been created in the new illumination section, where the extensive collections have been rearranged by reducing the number of exhibits and showing them in brightly lit cubicles, interspersed with dioramas to give a better idea of the effectiveness of the lighting that could be obtained from the apparatus available at various periods of history.

One of the most interesting developments of recent times is in connection with the expansion of the collection dealing with gas manufacture and distribution. In 1937, on the initiative of the late Thomas Hardie, at that time chief engineer to the Gas Light and Coke Company and a member of the advisory council of the Museum, a committee representative of gas producers and gas plant manufacturers was formed, and was charged with the task of creating a collection of exhibits worthy of the industry. This provides a notable example of collective effort on the part of the industry for the benefit of the Museum's permanent collections. Considerable funds were subscribed, and the scheme was well under way when war broke out. The committee has recently been reorganized under the auspices of the Institution of Gas Engineers, and development is actively proceeding on the basis of increased financial resources provided by the Gas Council. A large gallery, at present in course of completion, has been allotted to the subject, and the display will be on modern lines. It is expected that the work will have advanced sufficiently to enable the gallery to be opened in May or June this year.

Mining, though of such great national importance, has hitherto been poorly represented in the Museum. It is hoped, however, to open new mining galleries in the basement early next year, the main feature being a realistic representation of the galleries of a coal mine, with about 70 yards of roadway and a coal face of some 30 yards. Full-sized equipment will consist of conveyors, coal-cutters, cage, tubs, etc. This work is being carried out by the Museum with most valuable assistance from individual manufacturers of mining equipment. There will also be a metalliferous stope.

Electrical engineering is another important subject which, though rich in historical material, is poorly represented on the modern side. It is due for reorganization, so that its technical achievements and general significance may be better understood by the Museum's visitors, and a committee of the Institution of Electrical Engineers, on which all sides of the industry are represented, is assisting the Museum in this task. A gallery of 10,000 sq ft will be made available for the purpose when the Festival of Britain authorities release it.

The Museum possesses much valuable material illustrating the history of line telegraphy and telephony, and of radio communication, and a selection of apparatus developed during the war.

With the increase in the number of visitors which followed the opening of the new galleries in 1928, it was felt that something more should be done for the young, and those unacquainted with the principles of science. This led to the setting out of a Children's Gallery, designed to make them see the development of science as a connected whole, by means which make a strong appeal to children, such as dioramas and working exhibits. The printed guide to this gallery forms an admirable short introduction to the development of science, as is shown by the fact that some eighty thousand copies have been sold.

It is evident that considerations of space alone prevent the full and detailed display of modern scientific and technological developments. No more than a selection or general outline of these developments can be given in the permanent collections. The Science Museum recognizes an obligation, however, to do more than this, and accordingly from time to time special temporary exhibitions are held, lasting from a few weeks to perhaps six months, the purpose of which is to bring to the notice of the public all that is new in some relatively restricted field. A large number of such exhibitions have been held during the last thirty years, dealing with such varied subjects as geophysics (1924), adhesives (1926), glass technology (1931), very low temperatures (1936), television (1938), illumination (1950), and submarine cables (1950). The Museum is greatly indebted to industrial and scientific bodies and individual firms, who commonly shoulder a very considerable part, and in many cases a predominant part, of the expense and labour of organizing these special exhibitions, a commendable feature of which is the anonymity of individual exhibitors. Temporary exhibitions of a different character are those marking anniversaries of notable achievements in the fields of pure or applied science, and the exhibition recently held for the exclusive benefit of blind persons and those with impaired vision.

With the Science Library we pass, in conclusion, to a unit with an impact on the scientific world rather different from that of the rest of the Museum. The Science Library started well back in Victorian days, but it began to play its present highly significant role only during the late twenties of this century, when it first lent widely to scientific institutions and industrial research units (though not to individuals). At the same time it began rapidly to expand its holdings, especially of periodicals. It covers every subject in pure and applied science except medicine, though it has never catered for the more elementary reader.

The loan system was, from the first, the sort of runaway success which is perilously near to a disaster: borrowers were constantly on the point of using their privilege so freely that the unfortunate visitor to the reading room too often found the fatal notice 'On loan' confronting him. Until the second world war, however, this peril was kept in check, and the library, with its practice and advocacy of modern techniques of classification, information service, and the like, became a centre of pilgrimage for librarians from all over the world. Even the outbreak of war did not at once reveal the difficulties which lay ahead: readers naturally diminished in numbers, while the service to borrowers became a major asset to the nation, when so many new research units completely without library resources were being started for urgent war necessities. It was only after the war, when difficulties multiplied everywhere, that the demands on the library became almost unendurable in their effect on readers, and indeed on borrowers too. The library has brought into being a photocopy service and a co-operative lending service among its borrowers in an effort to check the chronic over-use of its collections, but years of work remain to be done, not least in reader-education, before it can measure up to the need which it has striven to supply and has no doubt in part created.

We have now surveyed the multifarious activities of the Science Museum and turn to look to its future. If the country's urgent needs do not prevent the fulfilment of the plans for the Museum's development, we look forward to a great extension both of the subjects illustrated and of the number and variety of exhibits used to that end. Whatever the rate of its expansion, however, the Science Museum will play its part in that revolution in museum technique which is going on all over the world at the present time. The *gazophylacium* and 'cabinet of curiosities,' beloved of the seventeenth century, gave way to the scientifically ordered but lifeless assemblages of objects characteristic of the nineteenth. Today we are discarding 'collections' in favour of integrated displays, designed not so much to show things as to express ideas by them, and by every device capable of making impressions on the human mind. Nor are these expressions of ideas to be simply intellectual, for we seek to appeal not only to the intellect that grasps the concepts of science, but to the aesthetic and emotional powers which lend significance to those concepts and make them a part, not only of the system of science, but also of the life of man.

The physics of clouds and their precipitation

P. A. SHEPPARD

Studies of the physics of clouds carried out within the last decade have thrown much light on the processes involved in precipitation, and lead to the conclusion that in most instances a raindrop originates as an ice crystal. This has led to attempts to initiate the precipitation of clouds artificially, either by the creation of ice nuclei or by the introduction of crystals, such as those of silver iodide and cadmium iodide, which possess a very similar crystal lattice.

Clouds are formed in the atmosphere by the quasi-adiabatic cooling of moist air due to its ascent; the form of the cloud depends on the nature and pattern of the vertical motion. If the latter should extend over a large horizontal area, of the order of 10,000 sq km or more, the vertical velocity is generally quite slight—no more than a few cm/sec—and a cloud of layer-type (stratus cloud) will be formed. If, on the other hand, the upward motion is quite local, of the order of 1 sq km, the velocity being large (up to 1000 cm/sec) or small, a heap of cloud (cumulus cloud) will be formed. Continuity and the conservation of mass demand that in both cases there should be descending air near the rising current. The descent involves compression and heating, and consequently evaporation of any cloud previously formed in the descending air; it is generally more gentle and extensive than the corresponding ascent.

This broad classification requires subdivision if it is to encompass adequately all the varied forms of cloud. Thus, lesser movements are often associated with the main one, giving rise to combinations of layers and heaps (stratocumulus, altocumulus, and cirrocumulus cloud), while, as will be discussed later, the temperature of formation and the depth of the rising current exert profound influences on the form and life-history of a cloud.

THE GROWTH OF CLOUD DROPLETS

We know, from the work of C. T. R. Wilson and others, that cloud droplets will not form in pure moist air which has been cooled, unless the relative humidity rises to a value several times that of saturation; the condensation then occurs on gaseous ions. Such supersaturations never occur in the atmosphere, because it always contains a more or less plentiful supply of microscopic or ultra-microscopic particles, often hygroscopic, upon which condensation can occur at relative humidities which need be at the most only slightly above 100 per cent. For the larger, hygroscopic particles Wright [1] and others have shown that condensation occurs at appreciably lower humidities. Some of these nuclei of condensation are particles of common salt of the order of 1 μ or less in diameter; Dessens [2] has caught the droplets on fine spider-thread (see figure 3) and examined their behaviour in an atmosphere the humidity of which was controlled. They often remain liquid at humidities far below the equilibrium value for a saturated solution of salt, and then consist of droplets of supersaturated solution. Sooner or later, however, crystallization sets in; the larger the droplet the more readily it occurs, and it happens with explosive violence, so that several smaller nuclei are produced simultaneously. Simpson [3] has argued that the oceans cannot produce salt particles at a rate fast enough to provide all the centres of condensation necessary in air in which cloud is formed, and from which the water is later precipitated. Oxides of nitrogen, formed presumably in lightning discharges and later dispersed widely, may perhaps provide alternative, but smaller, hygroscopic centres, while dust particles which can be wetted may act as non-hygroscopic nuclei. Further work is needed to solve the problem, but we may proceed by assuming that there is, in the rising air mass, a supply of condensation nuclei of various sizes at a concentration rarely numbering less than a few hundred per cubic centimetre. The number of nuclei can be measured with an Aitken nucleus counter. In populated areas, there are generally many thousands per cubic centimetre, formed as a result of combustion, but most of them are very small and probably unimportant.

The process by which hygroscopic nuclei grow in a rising current may be inferred from figure 4*a*,

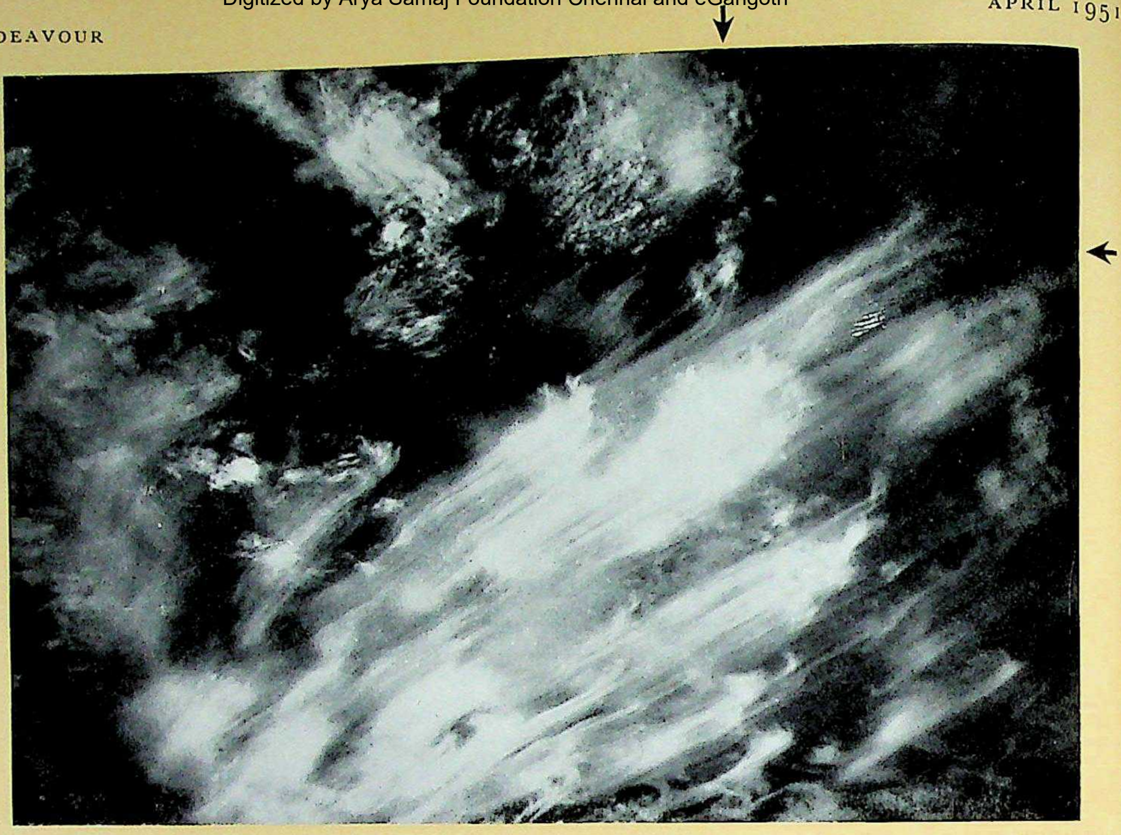


FIGURE 1 – *An example of cirrus (ice-crystal) cloud which has resulted from the earlier formation of supercooled water-droplet (cirrocumulus) cloud. The transformation is almost complete but a patch of cirrocumulus remains (top centre) and an element is in process of transformation on the lower right-hand side of this patch (see arrows). At temperatures of formation below* $-40°$ *C the precursor liquid phase is less readily seen.*

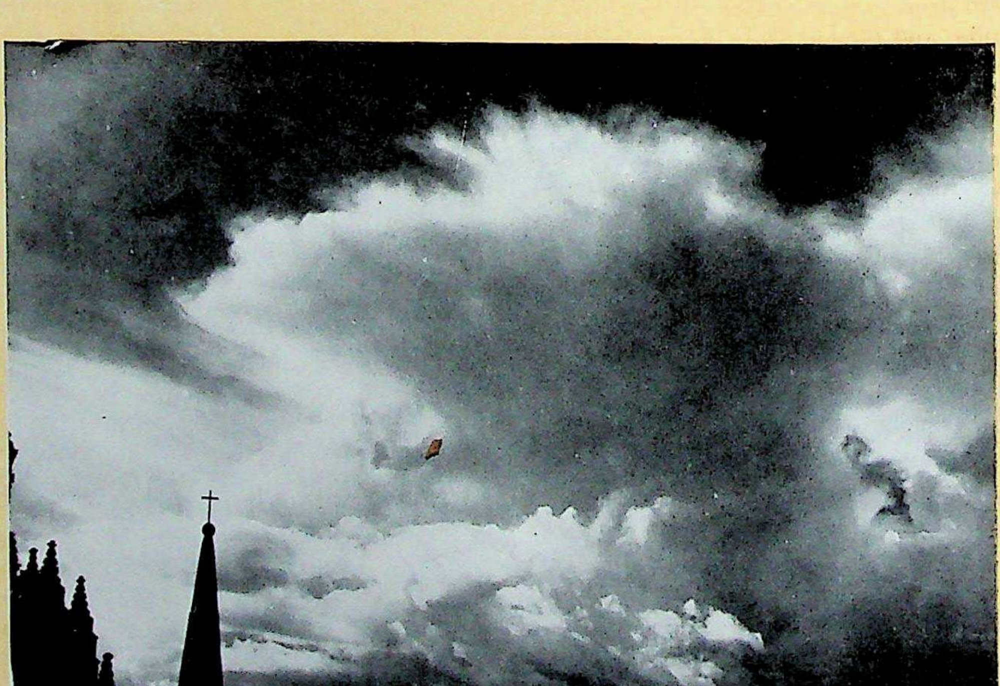


FIGURE 2 – *A cumulonimbus cloud, with well-developed anvil, which has been more or less completely transformed to ice. The cloud has probably passed into the decay stage, though rain continues to fall from the base.*

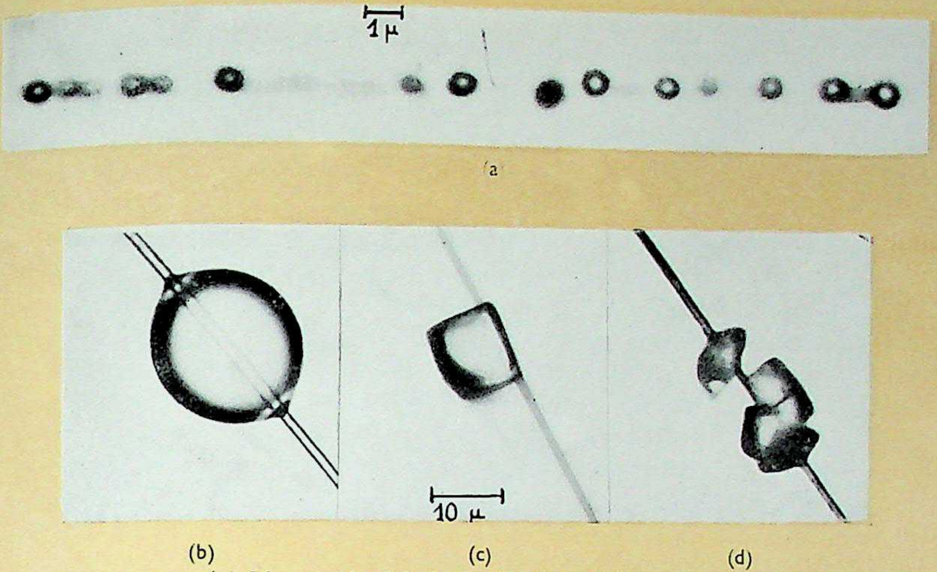


FIGURE 3 – (a) *Photograph of the larger droplet-nuclei from haze.* (b), (c), (d) *Photographs of a large droplet-nucleus before* (b) *and after* (c, d) *desiccation. Note the splitting in* (d). (*After Dessens.*)

(*Figures 1, 2 and 3 by courtesy of the Royal Meteorological Society.*)

which shows the equilibrium humidity over drops, containing varying concentrations of solute, as a function of their size. Two opposing effects determine the form of these humped curves: the depression of vapour pressure over a salt solution, which for a given drop is greater the more concentrated the solution, and the elevation of vapour pressure over a curved surface of pure liquid, which increases as the size of the drop diminishes (Kelvin effect). Note that each curve lies wholly above or below the next, and that the hump of supersaturation fades out for the nuclei containing larger amounts of solute. Condensation will occur on any drop if the actual vapour pressure in the air exceeds the equilibrium value for its radius, and the rate of increase of diameter is proportional to this excess vapour pressure, and inversely proportional to the diameter. This follows from the law of diffusion to a spherical body. The extent of the excess vapour pressure will in turn depend on the rate of ascent and the temperature, i.e. on the rate at which water vapour becomes available for condensation, on the number of drops per unit volume, and on their diameter (figure 4*b*). The growth-rate can then be readily calculated.

An actual case, in which nuclei of different sizes and different concentrations are involved, is more complex. All nuclei initially grow as the humidity rises to near-saturation, but only those in which the solute exceeds a certain concentration are able to surmount the hump in the equilibrium curve, because the actual super-saturation will depend on how rapidly the available water vapour is taken up by the faster-growing nuclei. For those which pass over the barrier, the growth rate thereafter depends on diameter in two opposing ways: the excess vapour pressure is greater over the larger drops (*cf. BB′ and CC′* in figure 4*b*), but for a given excess of vapour pressure the smaller drops increase their diameter by diffusion more rapidly than do the larger ones. Differential growth rates are therefore not obvious, and only detailed computations for given nuclear spectra, rates of ascent, and temperature can enable the outcome to be predicted.

Such computations have been made by Howells [4] for low, moderate, and high rates of ascent, assuming a range of nuclei likely to be encountered in practice; he finds a strong tendency towards homogeneity in a cloud quite early in its history. Only the largest, amounting to between 10 and 20 per cent. of the total nuclei, become drops; the higher rates of ascent involve the greater fraction of nuclei and the greater uniformity of size of drops. The latter conclusion receives support from the appearance of lenticular altocumulus clouds in the standing waves which form down-wind from some topographical features. Very considerable vertical velocities are encountered in these waves, and the clouds show coronal iridescence,

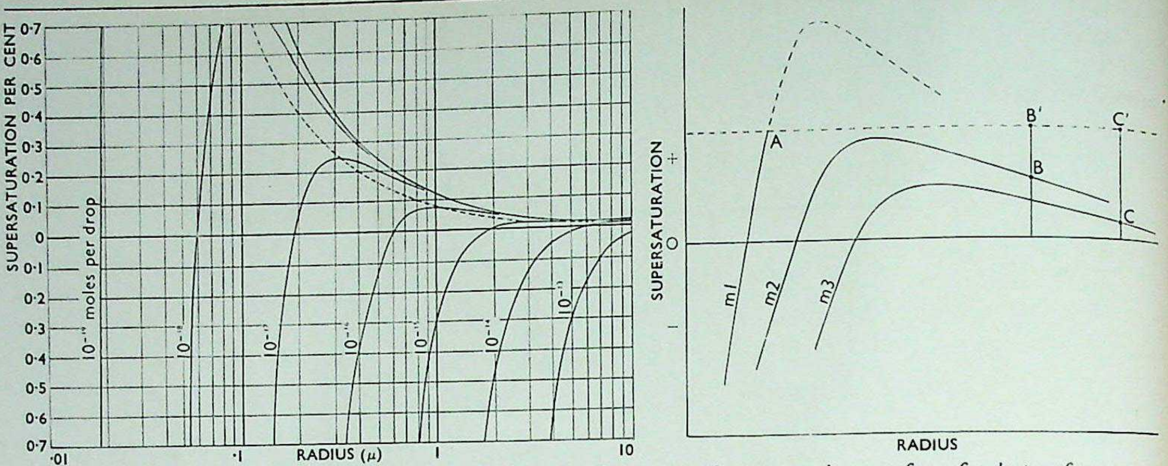


FIGURE 4 – (*left*) *Equilibrium humidity, shown as departure from saturation over a plane surface, for drops of water containing given amounts of dissociated solute, measured in moles per drop and thus independent of the nature of the solute* (*after Howells*). (*right*) *An exaggerated portion of graph to show the growth process. The horizontal broken line represents the humidity in the environment of the drops at a given instant. Nucleus* m1 *is in equilibrium with its environment at* A *and does not grow; nuclei* m2 *and* m3 *are assumed to have reached the points* B *and* C *respectively and are subject to excess vapour pressures represented by* BB′ *and* CC′, *and they therefore grow.*

indicative of cloud homogeneity. Howells finds the supersaturation in a growing cloud to be small at all times, with a maximum of about 1 per cent. in rapidly rising currents.

Observations on the diameters and concentrations of droplets in clouds are still rather few and perhaps not very reliable. There are usually a few hundred drops per cubic centimetre, with diameters covering a considerable range at any one part of the cloud. There are, however, always fairly well-defined maxima in the diameter-distribution and drop-volume-distribution curves—evidence of the tendency towards homogeneity. The position of the maximum varies from one part of the cloud to another, and depends on cloud type. It is found that the diameter of droplets may vary from about 2 μ to 50 μ (or more in precipitating clouds) with the diameter of the drop with median volume generally falling to between about 6 μ and 30 μ. In this respect clouds range themselves roughly in the order: stratus (minimum), stratocumulus, cumulus, altocumulus, nimbostratus, cumulonimbus (maximum). See Bricard [5], Diem [6], and Lewis and Hoecker [7].

The distribution of drop-size will be modified near the edges of cloud by turbulent mixing with clear air, causing a wider range of sizes, and to some extent also within the cloud by the collision of drops, a process calling for further investigation. Most workers are at present agreed that collisions are too infrequent to modify appreciably the basic distribution within the lifetime of most cloud droplets, provided that large drops are not produced.

We may show by a simple argument that large drops are not readily produced by a condensation process. Consider, for example, a very favourable case in which warm air of high relative humidity, and therefore of high absolute humidity (say 25° C, 70 per cent. humidity), and with low effective nucleus content (100 per cubic centimetre), is transported upwards to such a height that practically all the water vapour is condensed. The resulting drops, assumed to be uniform, will, it may be shown, attain a diameter of less than 70 μ. For comparison, a drizzle droplet has a diameter of 200 μ or more. Such sustained ascent would, of course, take the air to levels at which the temperature is well below 0° C, but supercooling to a minimum of −30° C is fairly general in the atmosphere, so that the assumption that water is condensed throughout the ascent considered is reasonable.

We are thus led to the conclusion that clouds of water drops are in general colloidally stable, and may not produce rain unless there is present some agent, so far unconsidered, that will cause an aggregation of the cloud droplets. One such agent is ice, and this leads us to discussion of the production of clouds containing ice-crystals.

ICE CLOUDS

We have just remarked that water droplets supercool in the atmosphere. They are also formed on nuclei at sub-zero temperatures, but it appears that below about − 40° C condensation always occurs in the form of ice, giving rise to those beautiful thread-like cirrus and halo-forming cirrostratus clouds of high levels. Even here, however, the evidence is that an ice crystal forms only on a nucleus which is first appreciably wetted in an atmosphere saturated with respect to water, i.e. about 50 per cent. supersaturated with respect to ice (see figure 1). The atmosphere is frequently supersaturated with respect to ice, but unsaturated with respect to water, without ice cloud being present. Persistent aircraft condensation trails show up this state of affairs. The aircraft exhaust provides sufficient water vapour to produce saturation with respect to water in the aircraft's wake; the nuclei then grow and an artificial ice cloud is formed. Fournier d'Albe [8] has watched this process with the ultramicroscope, using an expansion-chamber in which the end-point could be closely controlled at the frost-point or dew-point of the air. He found that whereas ice only was formed at temperatures below − 41° C, a few ice crystals appeared among many more water droplets in the range − 32° to − 41° C when uncleaned air was used. He also discovered two kinds of artificial nuclei, silver iodide and cadmium iodide, possessing much higher threshold temperatures for ice formation, about − 7° and − 9° C respectively, the latter temperature, however, only if the cadmium iodide had first been activated at − 41° C or below. Moreover, this salt then behaved as a true sublimation nucleus, i.e. it became active at the frost-point; it is the only sublimation nucleus, apart from ice itself, so far discovered. Both substances have lattice constants quite close to those of ice I.

Findeisen [9] had earlier discovered the existence in the atmosphere of ice-forming nuclei which become active at about − 10° C, but in concentrations so low (of the order of one per litre) that they could not be found in Fournier d'Albe's small expansion-chamber. They are, as we shall see, likely to be of great importance in promoting colloidal instability in supercooled-water clouds. There is no definite knowledge of the nature of any of the ice-forming nuclei in the atmosphere, but Mason [10] has made tentative inferences. The expansion-chamber technique so far used in their examination involves the equivalent of excessively high rates of ascent of air, and, as Findeisen found the activity of nuclei to depend on the rate of expansion, there must be some hesitation in applying the results of such research directly to the atmosphere. We may infer, however, that most, if not all, clouds of supercooled drops will contain a very small percentage of ice particles at temperatures between about − 10° C and − 30° C, and a greater percentage below − 30° C. At temperatures below − 41° C all clouds are probably composed mainly if not wholly of ice.

THE PRODUCTION OF PRECIPITATION

We have already seen the relative humidity in a cloud composed of water to be practically 100 per cent. with respect to water, and the presence of relatively few ice crystals cannot substantially alter that state. Such ice crystals therefore find themselves in a supersaturated atmosphere, and consequently grow at the expense of the water droplets, the maximum growth rate, *ceteris paribus*, occurring at − 12° C. Growth being rapid, they quickly acquire a substantial rate of fall relative to the surrounding cloud droplets, and a sweeping action ensues, so that growth is much enhanced. In deep layer-type clouds (nimbostratus), with small rates of ascent of air, these units of precipitation are mainly snowflakes, while in vigorous convection clouds (cumulonimbus) they are more likely to be graupel (granular snow pellets or soft hail), since these are the preferred forms when growth is rapid. Melting will of course begin as soon as 0° C is exceeded during their fall, and, if cloud extends below this level, growth will continue by the sweeping action alone, which preponderates from a much earlier stage. The precipitation may reach the ground as rain if there are a sufficient distance and rise of temperature between the 0° C level and the ground.

The essence of these ideas was first put forward by Bergeron in 1933. They may be summarized thus: every raindrop originates as an ice crystal. It has recently been shown that the concentration of ice-forming nuclei at the higher temperatures is of the right order of magnitude for the process described, though other processes of rain-production should not necessarily be excluded. For example, there is accumulating evidence that some convection clouds, particularly in the tropics, produce rain without rising above the 0° C level. Ludlam (unpublished) has suggested that this may happen when there is a small fraction of particularly large hygroscopic nuclei which grow preferentially, and, in moving up and down vertically, remain long enough in the cloud to grow to the size of raindrops, even large raindrops, by sweeping action alone. The circumstances require quantitative treatment before a conclusion can be reached. It is readily shown that sweeping action may produce a rapid rate of growth. Thus if there are relatively few larger drops, of diameter D, falling through a cloud of smaller drops whose liquid water content is w per unit volume of cloud, the rate of increase of D is of the order of 0·5w per unit distance of fall relative to the small drops. Taking a quite moderate value for w of 1 gm per cubic metre in a convection cloud, the rate of diameter growth is 0·5 mm per kilometre.

Ludlam [11] has also pointed to the possibility of a chain reaction in cumulonimbus clouds. Initially small graupel or hailstones may collect water by sweeping at so fast a rate that the latent heat of fusion may not be entirely dissipated, and supercooled 'raindrops' stream from the rear of the element. These may grow by further sweeping action, become unstable and break into smaller drops, and so on. In that case the ice crystals appearing near or at the summit of a cumulonimbus cloud (figure 2) perform no necessary function in the main release of precipitation, though they may account for the rather light rainfall in the decay period of a storm. When the concentration of ice particles is high, the Bergeron process must in any case be less effective, for there is then much less water available per ice crystal than when the ice crystals are rare.

ARTIFICIAL PRECIPITATION

The realization that precipitation is produced by a trigger action has led to much recent work, initiated by Langmuir, on the artificial triggering of clouds. This has taken two forms—the unloading of small pellets of solid carbon dioxide from aircraft into supercooled clouds, and the introduction of silver iodide nuclei from the ground into clouds by convection. The carbon dioxide pellets produce a copious supply of ice crystals in their wakes by local cooling, and large patches of a supercooled layer-cloud may thus be dispersed by transforming the cloud into snow. It also appears that large cumulus clouds have been caused to rain by the same method, or by silver iodide inoculation, but it must be realized that such clouds might produce precipitation in any case—there is only a quite narrow band of cloud-top temperatures in which artificial seeding can be used to anticipate natural seeding. If, however, seeding is not the only possible method of triggering a cloud, as is indicated by the natural precipitation from unglaciated clouds, the possible scope of artificial precipitation is somewhat widened. Whether precipitation is produced naturally or artificially, a large quantity of liquid water must be present in a vertical column drawn through the cloud. It is aided by high temperature at the base (high dew-point of the air supply), great depth (long distance in cloud for embryo precipitation elements to fall through), and large upward vertical velocity (long time of fall of precipitation elements through a given depth of cloud).

NEW METHODS OF CLOUD INVESTIGATION

The experiments recently undertaken on the artificial precipitation of clouds may be regarded as an extension of the usual physical laboratory procedure of controlled experiment, which is not often applicable in meteorology. Thus, whatever may be their outcome so far as rain-making (or even rain-prevention) is concerned, meteorologists should learn much about cloud physics from such experiments.

Centimetric radar has recently placed another powerful tool in the cloud physicist's hand. A cloud scatters back radar pulses according to the Rayleigh law, that is, with an intensity proportional to $\Sigma(nd^6)$, where n is the number of drops of diameter d in the beam. Thus radar provides a technique of cloud exploration (particularly for cumulonimbus, for which the aeroplane is a rather fragile tool) which is particularly suited for the identification of larger cloud elements and so can be applied to the study of precipitation growth, echoes being obtainable from particles of both water and ice. The life-cycle of cumulonimbus clouds is of the order of an hour, and so can be followed on a single radar set. Much has been learnt about this cycle since the war, but only passing reference (Sheppard [12]) can here be made to it.

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Antibacterial substances from lichens

FLORENCIO BUSTINZA

Recent investigations have shown that crude extracts of many lichens, and some of the individual lichen acids, such as usnic acid, have considerable antibacterial activity, including activity against the tubercle bacillus. Experiments with animals indicate that some of these substances may prove suitable for chemotherapy, particularly for combating infections resistant to currently used drugs. These interesting discoveries give some justification for the traditional use of lichens, in many different countries, for treating certain pulmonary affections.

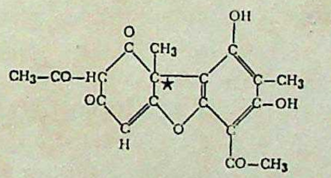
There are not many references to the use of lichens in medicine in ancient times. It has been recorded that while travelling in the Nile Valley in 1864 Schweinfurth found a fragment of lichen in a vase of the 18th dynasty (approximately seventeenth century B.C.). This lichen was identified by Muller as *Evernia furfuracea* (L.) Ach. It is interesting to note that a crude extract of this species has recently been shown [1] to be active against the bacterial species *Staph. aureus*, *Bacillus mycoides*, *B. licheniformis*, and *Mycobacterium phlei*. Another lichen, *Lobaria pulmonaria* (L.) Hoffm., has a long-established reputation in medicine; from the 17th to the 19th centuries *Cetraria islandica* (L.) Ach. was widely prescribed for the treatment of pulmonary tuberculosis. In 1802 the French military physician J. B. Regnault published an interesting work entitled *Observations on pulmonary consumption or an essay on the lichen islandicus considered both as an aliment and as medicine in that disorder*. This species was included in many pharmacopoeias until quite recently, and it is interesting to note that crude extracts of it inhibit the growth of many bacteria, including several species of *Mycobacterium*.

In modern times Burkholder and his collaborators [2] were the first, in 1944, to call attention to the antibacterial activity of different lichens. They used for their assays, made by the usual plate and cylinder method developed for penicillin, crude extracts prepared by grinding up freshly gathered lichen with phosphate buffer at *p*H 7·4. As test organisms they used *Staph. aureus*, *B. subtilis*, *P. vulgaris*, *Str. faecalis*, and *E. coli*. A later paper [3] described additional tests made not only with fresh lichens but also with dried material from various collections. Of the several hundred species tested, fifty-two proved to be active against *Staph. aureus* or *B. subtilis*, but the great majority proved inactive against Gram negative bacteria; the exceptions are tabulated in the next column.

ACTIVITY OF LICHENS AGAINST GRAM NEGATIVE BACTERIA

Lichen species	*Active against*
Cladonia delicata; Cladonia glauca; Parmelia conspersa; Parmelia rudecta; Thamnolia vermicularis; Xanthoria parietiana . .	*A. faecalis*
Cladonia borbonica; Parmelia rudecta . .	*E. coli*
Parmelia physodes; Umbilicaria papulosa . .	*P. vulgaris*

The discovery of antibacterial activity in lichen extracts prompted examination of some of the individual lichen acids. The first of these was isolated by Pfaff in 1826 from *Cetraria islandica*. In 1843 Rochleder and Heldt isolated, from *Usnea barbata*, the important substance usnic acid, the chemical nature of which has been studied by Curd and Robertson and Schöpf and Ross. Hesse and Zopf subsequently isolated many more. The Japanese workers Asahina, Asano, and their co-workers have made detailed studies of the chemical nature of lichen products, and Asahina himself has made a notable contribution in this field by the development of microchemical methods for identifying lichen acids.



Burkholder and his co-workers showed [3] that a saturated aqueous solution of usnic acid is active against *B. subtilis* but inactive against *E. coli* and *Staph. aureus:* atranorin and fumarprotocetraric acid are inactive against both these bacterial species. In 1945 Barry and McNally [4] reported only slight activity of roccellic acid (α-methyl-α′-*n*-dodecyl-succinic acid) against *M. phlei* and *M.*

tuberculosis bovis. They found high activity in the monoesters and the monoamide of this acid, which is produced by *Lecanora sordida*.

Nolan and his collaborators have studied the chemical nature of diploicin, derived from *Buellia canescens*; they showed that it is a depside containing three organic chlorine atoms. In 1946 Barry tried to test its antibacterial action but found that it was insoluble in water; mild treatment with alkali, however, led to the appearance of a phenolic and a carboxylic group, and the derivative had a water-soluble sodium salt. This was active *in vitro* against *M. smegmatis*, *C. diptheriae* (*mitis*), and *M. tuberculosis* [5].

In 1946 Bargellini *et al.* [6] showed usnic and vulpinic acids to be active against *Staph. aureus*, *C. diphtheriae*, and *B. subtilis* but not against Gram negative bacteria.

Early in 1947 Marshak published interesting work on a crystalline antibacterial substance obtained from *Ramalina reticulata* (Noedh) Kremph. At a dilution of 1 : 20,000 this substance inhibited various species of *Pneumococcus*, *Streptococcus*, and *Staphylococcus*. At a dilution of 1 : 50,000 in Dubos medium various strains of *M. tuberculosis* were inhibited; in some tests appreciable inhibition was found even at 1 : 2,000,000. *M. tuberculosis avium* was more resistant to usnic acid than was *M. tuberculosis hominis*, as in Dubos medium it was necessary to have a concentration of 1 : 20,000 to obtain even partial inhibition of the *avium* strain. In an attempt to protect guinea-pigs against virulent strains of *M. tuberculosis* he concluded that a dose of 25–50 mg per kg of body-weight could be given daily, by subcutaneous injection in oil, without toxic effect. When so given to guinea-pigs infected intraperitoneally with human tuberculosis, the progress of the disease appeared to be retarded [7]. Subsequently Marshak [8] identified his material as the *dextro* isomer of usnic acid.

In 1947 Stoll and his collaborators described [9, 10] results of tests on 58 lichen species, of which 38 proved active against *Staph. aureus*; they discussed also the activity of usnic acid against *Mycobacterium* and other organisms (figure 5). This was the first published work to mention the activity of *Cetraria islandica* (figure 4), *Cladonia rangiferina*, *Lobaria pulmonaria*, and *Parmelia furfuracea* against *Staph. aureus*. These workers also described for the first time the extraction of *dl*-usnic acid from *Cetraria islandica*, the yield being 0·04 per cent.; they showed that its antibacterial activity is independent of its optical activity. All forms of usnic acid inhibited strains of *M. tuberculosis hominis* and *M. tuberculosis bovis* at dilutions ranging from 1 : 500,000 to 1 : 800,000. It was also shown that vulpinic, *d*-protolichesteric, dihydrolichesteric, physodic, and diffratic acids are all more or less active against *Mycobacterium* and Gram positive cocci. In 1947 Barry and his collaborators [11] reported the anti-tuberculous activity of usnic acid at dilutions of 1 : 500,000. In 1948 Ciferri and Giacomini published the results of a survey of 231 different lichens.

The author's own investigations in this field began, with A. Caballero, towards the end of 1947. Attention was first directed towards the activity of *Evernia furfuracea* and *Evernia prunastri*, using as test organisms *Staph. aureus*, *B. mycoides*, *B. licheniformis*, and *M. phlei*. From *Evernia furfuracea* we isolated an antibacterially active fraction rich in ergosterol; from *E. prunastri* we obtained usnic acid [1]. We also studied the antibacterial activity of *Usnea florida* (L.) Hoffm., and obtained from it *d*-usnic acid in yields of 3·8–4·1 per cent. of dry matter. The activity of this substance against *Staph. aureus* and *M. phlei* was assayed; when it is added as a fine powder to broth *Staph. aureus* is inhibited at a dilution of 1 : 50,000 and *M. phlei* at 1 : 100,000. *M. tuberculosis avium*, in glycerine broth, is completely inhibited at 1 : 100,000 and partially so at 1 : 200,000. In Dubos medium, however, much higher concentrations (1 : 20,000) are necessary to effect inhibition; a similar effect was noted with *M. tuberculosis hominis*. In glycerine broth this is inhibited at 1 : 500,000, but in Dubos medium a tenfold increase in concentration is necessary for the same result. When using the plate and cylinder method of assay for sodium usnate, large and very clear zones are given by 1 : 10,000 solutions, using *M. tuberculosis avium*. We have also described the formation of a precipitate, thought to be streptomycin usnate, when sodium usnate is added in aqueous solution to streptomycin hydrochloride. This substance, which we have used as a suspension in phosphate buffer or oil, or in solution in propylene glycol, is characterized by being active against all the species of *Mycobacterium* which were tested and in addition it is active against *E. coli* (figure 1). Since the publication of these results I have been able to demonstrate the presence of streptomycin in this precipitate by using it (figure 2) to promote the growth of streptomycin-dependent strains of *E. coli*. Conversely, the presence of usnic acid in the precipitate is demonstrated by the fact that it inhibits the growth of the pathogenic fungus *Tricophyton mentagrophytes*, which is susceptible to usnic acid but not to streptomycin (figure 3). At the time of writing it is not clear whether this precipitate is a chemical combination of usnic acid and streptomycin, or whether it is merely a physical combination held together by adsorptive or similar forces.

Curiously enough, at the same time as this type of research on lichens was being pursued in Europe and the United States, Japanese workers independently entered the same field. In 1948 Shibata and his colleagues [12] published the results of research on the antibacterial activity of *laevo*, *dextro*, and *dl* usnic acid and some of their derivatives, the latter including *l*-diacetylusnic acid, *d*-diacetylusnic acid, *l*-dihydrousnic acid, and *d*-diacetyldihydrousnic acid. Their results are tabulated below.

Derivative	*Inhibiting titre*	
	Staph. aureus	*M. tuberculosis avium*
Usnic acid	1 : 160,000–1 : 320,000	1 : 160,000
Diacetylusnic acid	1 : 10,000 –1 : 25,600	1 : 40,000
l-Dihydrousnic acid	1 : 10,000 –1 : 25,600	1 : 40,000
d-Diacetyldihydro-usnic acid . .	1 : 6,400 –1 : 10,000	1 : 10,000

These results suggest that the double bond and the hydroxyl groups contribute in large measure to the antibacterial activity of usnic acid. Marshak and his colleagues have since confirmed that any major alteration in the usnic acid molecule reduces or destroys its activity.

Shibata and his colleagues refer to the use of *Usnea longissima* in China as an expectorant, and for the local treatment of ulcers. They also state that more than fifty years ago tincture of *Usnea* spp. was successfully used for the treatment of tuberculosis lymphadenitis. In a subsequent publication Shibata and Miura [13] described an investigation of the action of 23 lichen products against *Staph. aureus* and *M. tuberculosis avium.* These substances had very varied chemical structures and included lactonic fatty acids, depsides, depsidones, and an anthraquinone derivative. They also found high antibacterial activity in certain tetronic acid derivatives, such as protolichesteric acid, and in certain depsides and depsidones related to orcinol. Later [14] they reported that didymic acid and a derivative of it are active against Gram positive bacteria; these substances contain the dibenzofurane nucleus.

In 1948 Klosa [15] gave an account of the antibacterial properties of a substance, which he named evosin, derived from one of the *Usneaceae*; evosin is in fact a mixture of usnic acid, evernic acid, and two other unidentified substances. Evosin is very active against both staphylococci and streptococci; it inhibits the growth of *M. tuberculosis* at a dilution of 1 : 2,000,000. Klosa states that evernic acid inhibits the same organisms at dilutions of 1 : 1,000,000. In subsequent publications [16, 17] he describes the successful clinical use of evosin in various skin diseases, such as lupus vulgaris, furunculosis, and impetigo, and in the treatment of bovine mastitis.

Vartia [18] states that in Finland hot aqueous extract of reindeer-moss (*Cladonia alpestris*, *Cladonia rangiferina*, or *Cladonia sylvatica*) is traditionally used as a remedy for tuberculosis. Of 82 species tested usnic acid was found in 22. These 22 species were all active against *Sarcina aurea*, *Staph. aureus*, *Strep. pyogenes*, *B. subtilis*, and *B. megatherium*; the majority were also active against *C. diphtheriae.* He also records that twenty species of lichens inhibit *P. vulgaris* and generally also *E. coli*; nine of these species contain atranorin. From atranorin he obtained a crystalline derivative which inhibits *Proteus vulgaris* at a dilution of 1 : 10,000.

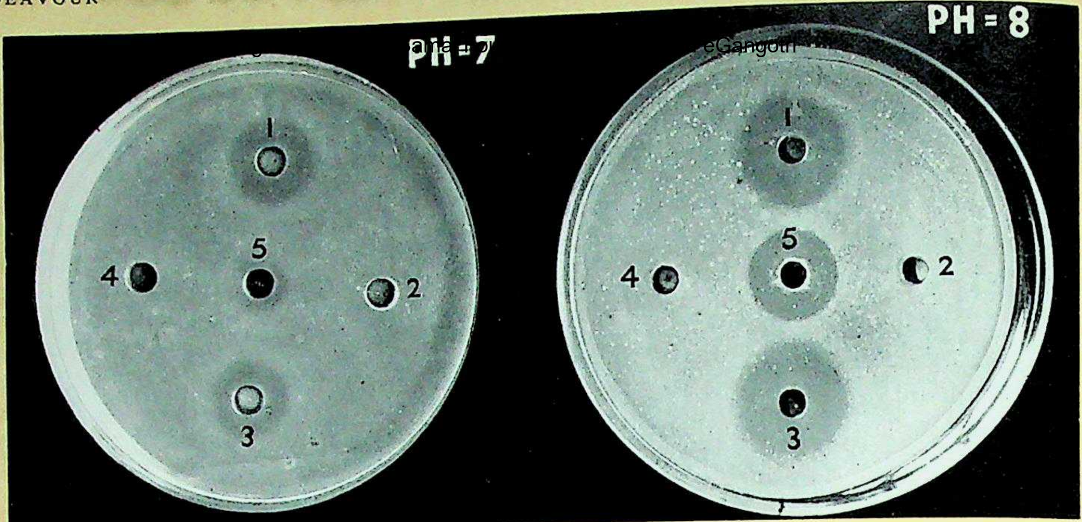
In a survey of the antibacterial activity of *Cetraria islandica* Vartia found it to be active against *Sarcina aurea*, *Staph. aureus*, *Strep. pyogenes*, *E. coli*, *P. vulgaris*, and *B. megatherium. Cladonia rangiferina* does not attack these organisms, according to Vartia, and Evans and Burkholder [3] state that *Staph. aureus* and *B. subtilis* also are not inhibited by this lichen; this conflicts with Stoll *et al.*, however, who found that *Staph. aureus* was attacked. Vartia also reports antagonism between the two groups of lichens and fungi tabulated below.

Lichen-fungus antagonism

Lichens	*Fungi*
Cetraria glauca *Parmelia stenophylla* *Evernia prunastri* *Usnea dasypoga* *Alectoria sarmentosa*	*Actinomyces sulfuroides* *Tricophyton farineculatum* *Tricophyton interdigitalis* *Epidermophyton inguinale*

Vartia states [19] that the sodium salts of protolichesteric, divaricatic, and physodic acids are active against Gram positive bacteria. Pätiälä confirms (private communication) Marshak's

eGangotri


PH-7
PH=8
1
2
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1
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3
4
5

FIGURE 1 – *Effect of* pH *on activity of streptomycin and streptomycin usnate.* (1) *and* (3) *contain a* 0·1 *per cent. suspension of streptomycin usnate;* (2) *contains a* 0·1 *per cent. solution of sodium usnate;* (4) *contains a* 0·1 *per cent. dispersion of usnic acid; and* (5) *contains aqueous streptomycin solution containing five units per c.c. The test organism is* E. coli.

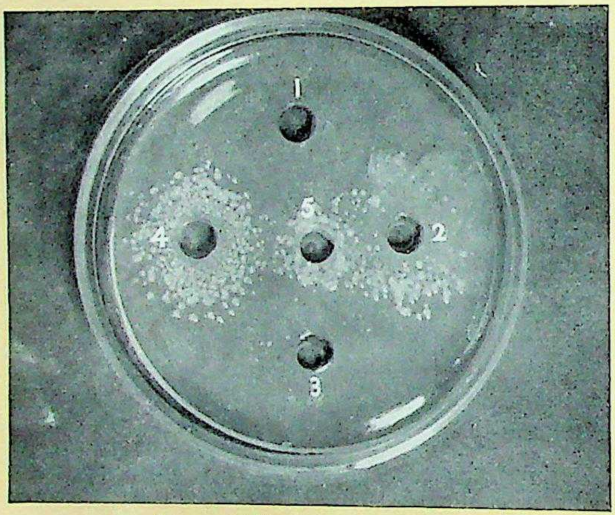

FIGURE 2 – *Plate seeded with streptomycin-dependent strain of* E. coli. (1) *and* (3) *contain* 0·1 *per cent. sodium usnate solution;* (2) *and* (4) *contain a* 0·1 *per cent. suspension of streptomycin usnate;* (5) *contains streptomycin solution containing eight units per c.c.*

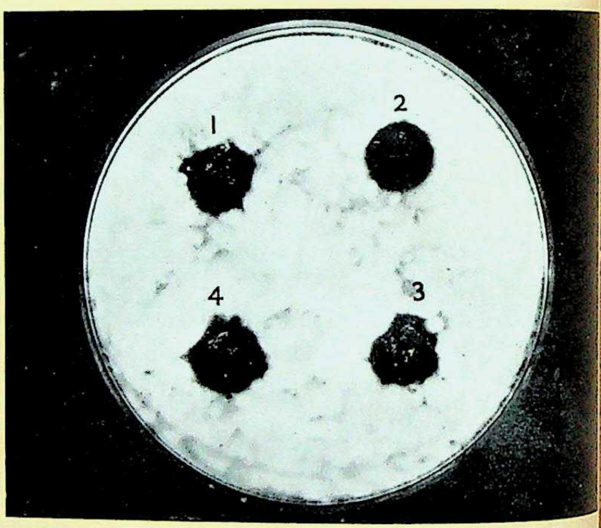

FIGURE 3 – *Plate seeded with* Tricophyton mentagrophyt *The holes were filled with a* 0·1 *per cent. solution of sodium usn*

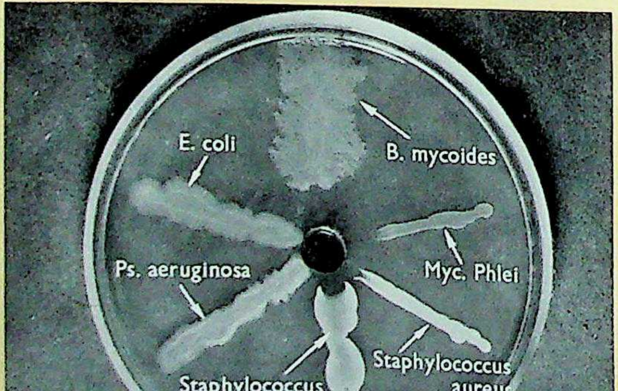
E. coli
B. mycoides
Ps. aeruginosa
Myc. Phlei
Staphylococcus aureus (Voureka)
Staphylococcus aureus N.C.T.C. No. 6571

FIGURE 4 – *Illustration of the inhibition of a number of bacterial species by a crude extract of* Cetraria islandica. *Note that* E. coli *and* Ps. aeruginosa *are not inhibited at all.*

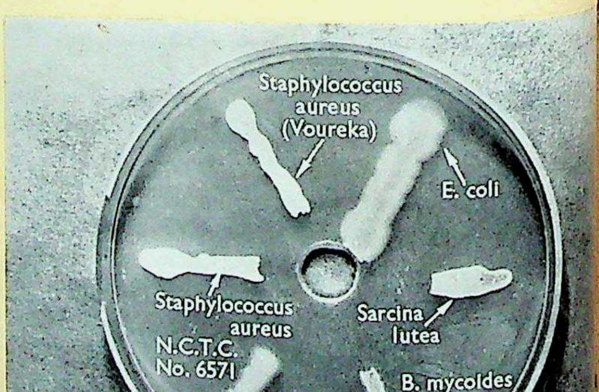
Staphylococcus aureus (Voureka)
E. coli
Staphylococcus aureus N.C.T.C. No. 6571
Sarcina lutea
B. mycoides
B. licheniformis

FIGURE 5 – *Illustration of inhibition of a number of bact species by* 0·1 *per cent. sodium usnate solution.* Staph. aur *(Voureka) is a penicillin-resistant strain. Note that* E. coli *is inhibited at all.*

observation that usnic acid retards the development of tuberculosis in guinea-pigs.

In more recent trials by Marshak and Kuschner [20] of the therapeutic value of usnic acid and streptomycin in treating tuberculosis in guinea-pigs, they conclude that 'although the results obtained show that streptomycin alone in sufficiently large doses is more efficient than usnic acid . . . the observed synergistic action of the two drugs makes it probable that the development of resistance, a serious problem in therapy, may be limited through the combined action of both substances.' This result is in agreement with my own prediction of 1948.

Despite the considerable amount of work reviewed here, which has led to the discovery of several promising new antibacterial substances, of which usnic acid has been the most closely studied, it is still not clear whether these substances are derived from the lichens as a whole or from the symbiotic fungi which form an integral part of them. Ashly, for example, has shown that the monomethyl ester of emodine obtained by Raistrick and his collaborators [21] from *Aspergillus glaucus* is identical with the product named physcion (= parietin) from *Xanthoria parietina*. Thomas [22] indicates that pure cultures of *Caloplacomyces*, a fungus occurring in many lichens of the genus *Caloplaca*, and also *Xanthoriomyces parietinae*, found in the lichen *Xanthoria parietina*, can produce physcion. From the fungus *Candelariellomyces vitellinae*, obtained from the lichen *Candelariella vitellinae*, he has isolated the substance stictaurin. Previously both stictaurin and physcion were regarded as products of the lichen rather than of the fungus. Castle and Kubsch [23] have isolated usnic, didymic, and rhodocladonic acids from the fungus found in the lichen *Cladonia cristatella*.

It is clearly of the greatest interest, in view of the promising results already obtained and the very urgent need for substances which will attack Gram negative bacteria, to continue a systematic study of the antibacterial and antifungal activity of the thousands of known lichen species; an important precaution which must be taken is to ensure that pure species and not mixtures are examined. Further, it is necessary to prepare and examine pure cultures of the fungi found in those lichens which yield substances likely to be of practical value. It may be that the fungi symbiotically associated with lichens will prove an important source of new antibiotics, some of which may be added to those which have already established themselves in medical practice. On the other hand, the lichens as lichens may prove a source of equally useful new substances.

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The permeability of animal tissues

G. M. WYBURN and P. BACSICH

The mucopolysaccharides, the protein-carbohydrate complexes which form the ground substance of connective tissue, are of great physiological importance Besides influencing the permeability of tissues, they are concerned in immune reactions and enzyme systems. Enzymes, such as hyaluronidase, which can break down mucopolysaccharides, have remarkable powers of increasing the permeability of tissues, and are used therapeutically to hasten the absorption of subcutaneous injections as well as for treating certain types of male sterility.

Cells, fibres, and intercellular material are the structural elements of the tissues of the body. Epithelial tissues form the lining membranes of internal and external surfaces and the functional structure of glands. They consist of sheets or columns of cells held together by a small amount of intercellular material or cement. The connective tissues include the supporting structures of the body, such as bone, cartilage, tendons, and ligaments, and the different types of tissues of loose or dense texture forming capsules, sheaths, and the general packing tissue of the body. These connective tissues are made up of a varying proportion of cells, fibres, and intercellular material or ground substance. The cells are generally discrete, and may be widely scattered, as in bone. The fibres may form a loose, wide-meshed network (for example, areolar tissue), or they may be aggregated in bundles to form a dense feltwork, obscuring the cells and ground substance, as in tendons and ligaments. The intercellular material or ground-substance of the connective tissues ranges from a semi-fluid consistency of varying viscosity to the solid matrix of bone, hardened by the incorporation of mineral salts.

The skin consists of (*a*) an external cellular epithelium, the epidermis, with a minimum amount of intercellular ground-substance, and (*b*) a deeper connective tissue, the dermis, where the fibres and cells are set in a more plentiful ground-substance. Over most of the body the skin is freely movable on an underlying, loose, subcutaneous tissue made up of cells and fibres scattered throughout an abundant ground-substance.

The permeability of a tissue is a passive, physical quality, distinct from the vital cell activities of secretion and absorption, and determined by the amount and consistency of the ground-substance. Epithelial tissues with their small amount of intercellular cement have a low permeability, while the most permeable tissues are those with few cells and fibres and a large quantity of ground-substance of low viscosity—for example, subcutaneous tissue. The connective tissue in general offers considerable resistance to penetration by foreign fluids, and this resistance is an index of its permeability.

There are wide variations in the permeability of the different tissues, and even of the same tissues, such as skin, in the different regions of the same individual. There are also considerable differences in tissue-permeability between individuals, determined to some extent by sex, age, hormone activity, and particularly by the sex hormones and the vitamins such as vitamin C.

Chemically, the ground-substance of the connective tissue, and probably also of the intercellular cement of epithelial tissues, belongs to the group of protein-carbohydrate complexes known as the mucopolysaccharides. Protein-carbohydrate substances have important functions in many aspects of animal economy; for example, they are concerned in immune reactions and enzyme systems, and their particular properties are due to the presence of bound protein or peptide residues. The mucopolysaccharides have a low protein content and are predominantly carbohydrate. Their aqueous solutions have a high viscosity, and they tend to become insoluble in water after dehydration.

Mucoproteins form another group of protein-carbohydrate compounds. They have a relatively high protein content and predominantly protein reactions. Gonadotropic hormones (from the pituitary gland), saliva, serum extracts, and the jelly of jelly-fish, are examples of mucoproteins. The mucopolysaccharides of tissue ground-substance are hyaluronic acid, and the sulphuric esters chondroitin sulphate, mucoitin sulphate, and hyaluronic acid sulphate (which is a mucoitin sulphate); they contain hexosamine and uronic acid. All, or any combination, of these substances may occur in a particular type of tissue.

Heparin, which is a natural blood anticoagulant widely distributed throughout the body, particularly in the liver, is a mucopolysaccharide containing a high proportion of sulphuric ester. Tissues whose ground-substance contain the sulphate mucopolysaccharides stain with metachromatic dyes such as toluidine or methylene blue. Sulphate-free hyaluronic acid does not give this histochemical reaction. Hyaluronic acid, while present along with other mucopolysaccharides in the ground-substance of connective tissues, is most abundant in the jelly-like vitreous humour which fills most of the eyeball; in the early umbilical cord connecting the embryo to the placenta; and in the lubricating synovial fluid in the cavity of movable joints. Hyaluronic acid sulphate is the mucopolysaccharide of the ground-substance of the cornea, the transparent covering of the front of the eye, and is responsible for its metachromatic staining. Chondroitin sulphate is the most readily accessible mucopolysaccharide occurring naturally. It is one of the major constituents of the ground-substance of cartilage, tendons, large blood vessels, and connective tissue generally, which therefore stain metachromatically.

The mucopolysaccharides have an architectural function in tissues. The most direct way of evolving bulk and viscosity is by polymerizing hexoses and sustaining them in water to form either a refractive medium (such as the vitreous humour of the eye and the synovial fluid of joints) or the undifferentiated substance of intercellular spaces.

It has been suggested that connective tissue cells secrete, into the surrounding tissue spaces, hyaluronic acid and a chondroitin sulphate, together with a precursor of collagen. By local acidification in the neighbourhood of the cells, the first fibres are produced by the action of the polysaccharides on the collagen, and the polysaccharides remain as a layer on the surface of the fibres. The production of mucopolysaccharides is probably a continuous process in metabolically active tissues such as the skin.

Any substance which acts chemically on mucopolysaccharides will alter the physical nature of the ground-substance and affect its viscosity, and thus also its permeability. Certain mucolytic enzymes found in animal tissues act on the mucopolysaccharides. They do this by breaking down the chemical linkages of the large asymmetrical polysaccharide molecules, and so increase tissue permeability largely by reducing viscosity. The first phase of this process is a depolymerization, and the final breakdown is of the nature of a hydrolysis. This reduction into simpler molecules effects a physical change in the ground-substance, which becomes less viscous and more permeable. The enzyme which has hyaluronic acid as its substrate is known as hyaluronidase, but as its action is not specific—for it can also break down the sulphate-containing mucopolysaccharides—it is probable that hyaluronidase includes a number of mucolytic enzymes. Because of their remarkable power of increasing tissue-permeability, these enzymes are known as spreading-factors.

Hyaluronidase is found in a number of tissues and organs, and enzymatic spreading activity has been demonstrated in extracts of such organs as testis, spleen, ciliary body, and iris. Both snake-venom and bee-venom possess spreading activity, and it is also exhibited by certain pathogenic bacteria. *In vitro*, mucolytic enzymes appear to act in three stages: (*a*) a separation of the protein residue, (*b*) a rapid depolymerizing action on the polysaccharide with diminution of the viscosity of aqueous solutions, and (*c*) a partial or complete hydrolytic action with liberation of N-acetyl-*D*-glucosamine and *D*-glucuronic acid. Their activity can be tested *in vitro* by physico-chemical methods, of which three have been described:

1. *The viscosity-reducing method.* One unit of the enzyme is defined as the amount required to reduce viscosity of the substrate mixture to 50 per cent. within 30 minutes.
2. *The mucin-clot prevention method.* Hyaluronic acid in an acid solution precipitates with protein to form a typical mucin-clot. Incubation with hyaluronidase first reduces the clot and the precipitate then ultimately clears.
3. *The turbidimetric method.* This method is based on the fact that depolymerized hyaluronic acid forms a clear solution with dilute serum, whereas pure hyaluronate is turbid.

In vivo activity can be tested by the spreading reaction. A dye, or Indian ink, is injected subcutaneously. Normally, after such an injection a blister remains, and the ink diffuses very slowly. If hyaluronidase or other spreading-factor is injected along with the ink, the blister flattens rapidly, and the ink spreads through the skin like fluid dropped on a blotter. If the animal, usually a rabbit, is killed 20 minutes after the injection, the minimal diffusion dose is the least amount of the enzyme which will produce a 20 per cent. increase in the average area of spread. If the animals are killed 24 hours after the injection, one finds that the ink has penetrated into the fascia and even into the muscle underlying the injected site. This spreading reaction can be obtained by other non-specific agents.

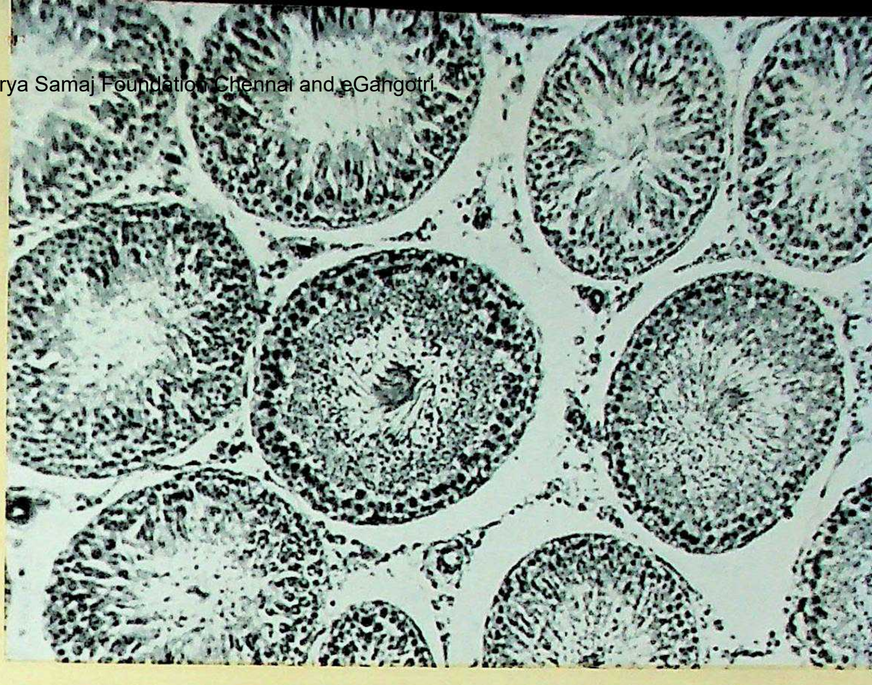
Hyaluronic acid has been extracted from the vitreous and aqueous humour in various animals, and hyaluronidase has been recovered from the ciliary body and the iris of the eye. There is some evidence for the constant production of hyaluronic acid in the eye, and its simultaneous removal, presumably by enzymatic hydrolysis. It is quite possible that this mechanism is in some way concerned with the maintenance of the normal tension of the eyeball. An abnormal increase in intraocular tension, resulting in the condition known as glaucoma, may well be related to some lack of equilibrium in the hyaluronic acid and hyaluronidase system. The polysaccharide of the corneal ground substance (hyaluronic acid sulphate) shows metachromatic staining by virtue of the sulphuric acid radical. The refractory media of the eye (cornea, lens, aqueous and vitreous humours) are avascular, and the continuous process of formation and breakdown of the polysaccharides of their ground-substance may have a nutritional significance. Considerable quantities of hyaluronic acid and chondroitin sulphate can be obtained from the skin. There is also a large concentration of hyaluronidase in the skin, which suggests a fairly rapid production and destruction of hyaluronic acid. It has been shown that, after injection of a spreading-factor, the skin barrier is reconstituted by production of new hyaluronic acid, and restoration is complete within 48 hours. This turnover is influenced by certain hormones. For instance, there are phasic changes in the sex skin of monkeys and apes corresponding to the sexual rhythm, and these involve alterations in the quantity and quality of mucopolysaccharides in the skin. In the turgescent sex skin of a baboon there is, during menstrual cycles, no free fluid, but water is bound by hyaluronic acid. These changes can be produced experimentally by injection of the appropriate hormone.

Hyaluronidase can be obtained from extracts of testes; the normal source of supply is bull testes. It is now known that hyaluronidase is formed in the seminiferous tubules of the testes, where the spermatozoa mature, and is conveyed to the sperms. The ovum, when shed into the Fallopian tube, has a thick covering or capsule of so-called follicular cells, which are cemented together by a viscous substance. This cellular capsule must be removed before the male sperm can penetrate and fertilize the ovum. Although only one sperm fertilizes the ovum, great numbers of them accumulate in the vicinity of the egg, and liberate the pre-formed enzyme. In a general way, the concentration of hyaluronidase is correlated with the number of sperms present. The cementing substance, binding the sticky mass of cells surrounding the ovum, is a mucopolysaccharide. The function of the hyaluronidase is to act on this polysaccharide, loosen and disperse the covering follicular cells, and so permit early fertilization of the ovum by the sperm. For example, without fertilization, i.e. in the absence of hyaluronidase, these covering cells adhere to the ovum for from six to eight hours, whereas following fertilization, i.e. in the presence of hyaluronidase, they disperse in about two hours. Modern work has shown that the optimum viability of the ovum is probably a matter of hours. It is therefore of importance that fertilization should not be delayed. The absence of hyaluronidase from the testes of birds, amphibia, and reptiles, is correlated with the lack of any capsule of follicular cells around their ova.

It is possible that deficient hyaluronidase is an occasional cause of male sterility. This is likely to be associated with a low spermatozoa count, but the accompanying enzyme deficiency may be a significant factor. Attempts have been made in such cases, before having recourse to artificial insemination, to produce a fertile mating by the addition of hyaluronidase to semen which has failed. Successes have been reported.

Pathological change in the connective tissues is the essential lesion in rheumatic diseases, including acute rheumatic fever, rheumatoid arthritis, and the great varieties and degrees of fibrositis grouped under the name of rheumatism. These changes include alterations in the quality and quantity of the mucopolysaccharides of the ground-substance. In affections of the joints, the synovial fluid contains an excess of hyaluronic acid. In this connection, recent work has shown that cortisone (compound E, the steroid from the cortex of the suprarenal) and adreno-cortico-trophic hormone (the secretion from the pituitary, which controls the secretion of cortisone), may act by protecting the connective tissues against the effects of whatever factor is responsible for the conditions in which the normal chemistry of the mucopolysaccharides has been disturbed. Changes in mucopolysaccharides are also an important part of the pathology of ageing and hardening arteries.

FIGURE 1 – *Section of testicle. In this field there are cross-sections of several seminiferous tubules, most of them showing active spermatogenesis (production of male germ cells). Apart from this function, the cells in the seminiferous tubules are responsible for the production of hyaluronidase, the presence of which is necessary in the semen of most mammals for the accomplishment of fertilization. This enzyme is probably produced by the Sertoli or nursemaid cells which are scattered in small numbers among the germinal elements of the tubule. The small groups of cells (interstitial cells), visible in the loose connective tissue among the tubules, produce the male hormone.* (× 110)



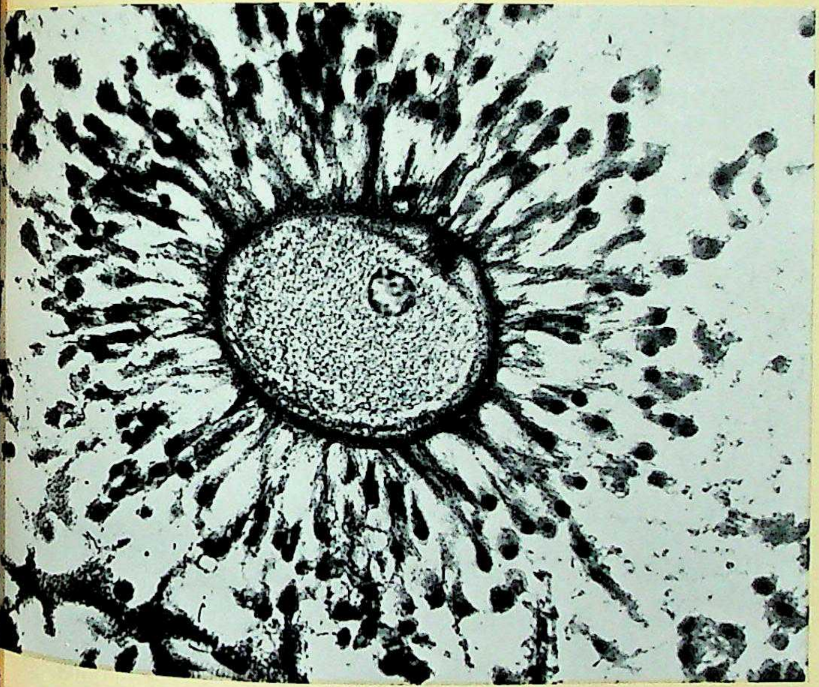
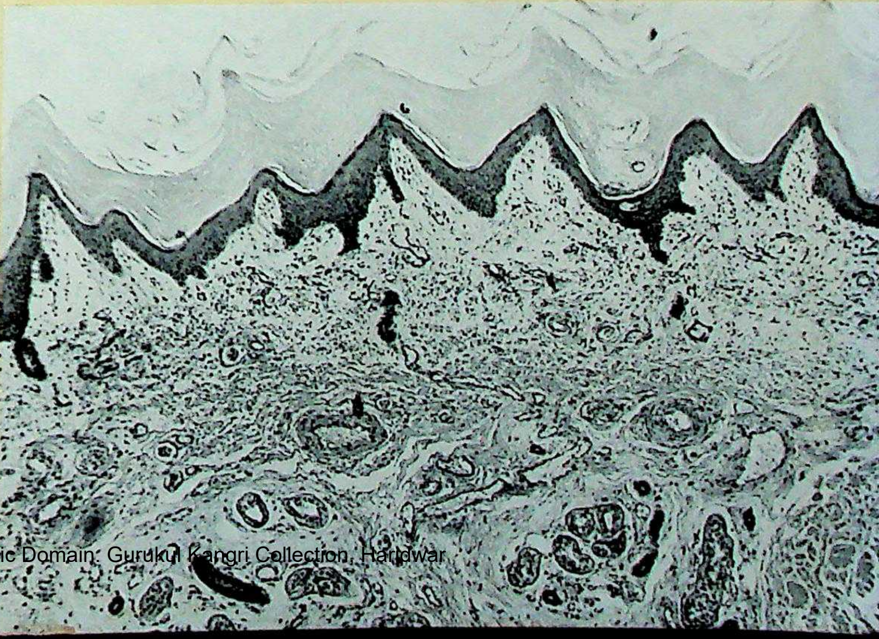


FIGURE 2 – *Section of a freshly discharged ovum (female germ cell). The ovum at this stage is surrounded by several layers of smaller cells derived from the ovarian follicle. As these cells would hinder fertilization they are gradually removed through enzymatic hydrolysis of the intercellular cementing substance by the action of hyaluronidase, brought along by the spermatozoa.* (× 300)

FIGURE 3 – *Section of skin. The surface of skin is covered by several layers of closely packed epithelial cells (epidermis) with very little intercellular substance. The uppermost layers of these cells are extensively cornified, consequently the epidermis protects the underlying soft parts (the dermis) from mechanical and chemical injury. The dermis contains numerous connective tissue cells and formed connective tissue fibres embedded in a hyaluronic acid jelly. The amount of this hyaluronic acid ground substance is noticeably reduced in exophthalmic goitre (increased activity of the thyroid gland) and consequently the skin as a whole becomes thinner. In myxoedema (reduced function of the thyroid gland) there is an accumulation of hyaluronic acid in the skin, which becomes thicker. These conditions strongly suggest the importance of the thyroid gland in the hyaluronic-acid/hyaluronidase relationship.* (× 52)



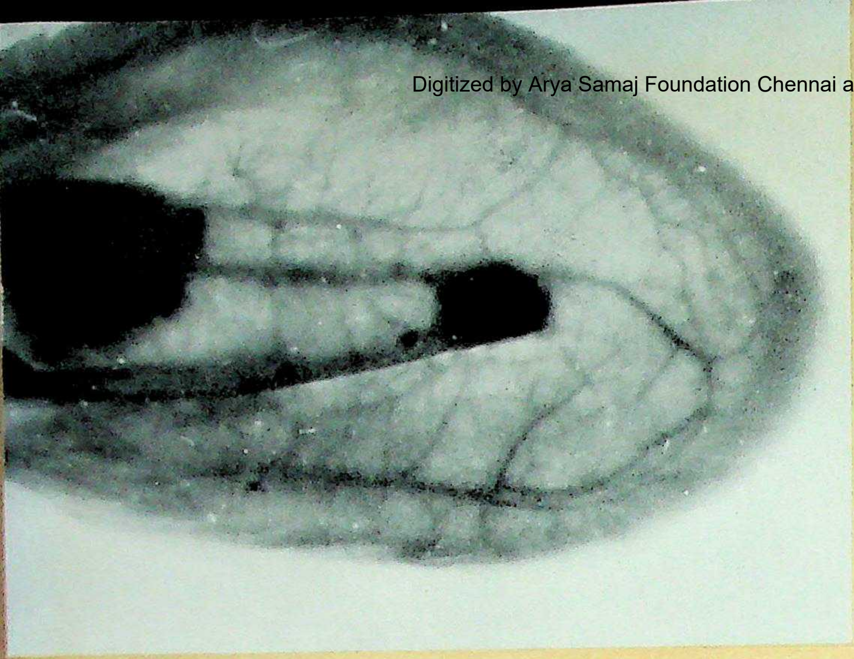


FIGURE 4 – *Photograph of a transilluminated rabbit ear to illustrate the spreading effect produced by hyaluronidase 20 minutes after the subcutaneous injection of two equal quantities of Indian ink. The smaller of the two dark patches is the result of injection of Indian ink diluted with physiological saline, while the larger one is produced by Indian ink diluted with a solution of hyaluronidase.* (× 1·125)

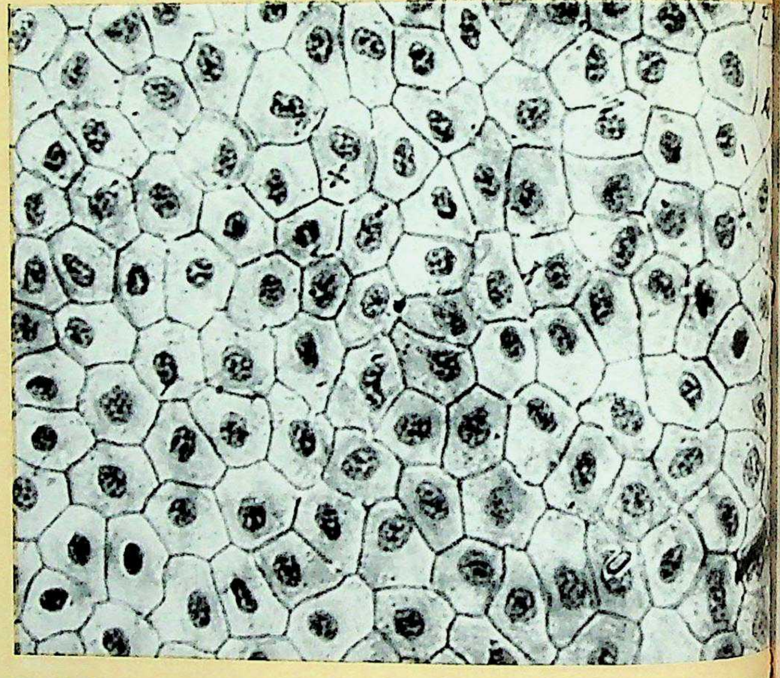


FIGURE 5 – *Surface view of the endothelial cells on the posterior surface of cornea. The intercellular substance (specially stained) forms only a thin cementing layer between the neighbouring cells. The anterior surface of the cornea is covered by several layers of epithelial cells. The main part of the cornea is formed by a jelly of sulphate of hyaluronic acid in which scattered corneal cells and fibres are embedded. There are no blood vessels in the cornea, as the mucopolysaccharide (sulphate of hyaluronic acid) maintains an avascular nutrition.* (× 225)

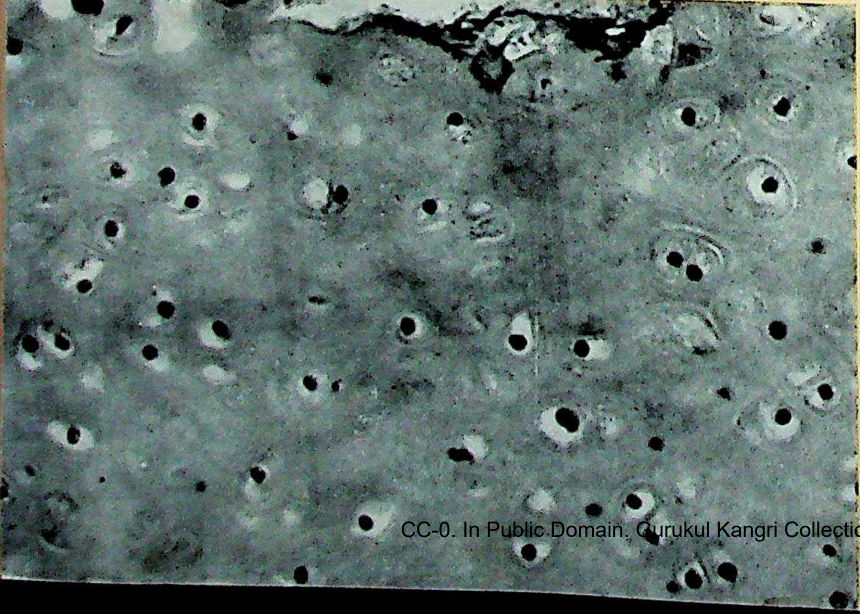


FIGURE 6 – *Section of hyaline cartilage. The ground substance is chiefly composed of a mucopolysaccharide, chondroitin sulphuric acid. In this ground substance are embedded small numbers of cartilage cells with darkly stained round nuclei and also preformed fibres. The latter are invisible owing to the similarity of their refractive index to that of the ground-substance. Observe again, as in the case of the cornea, complete absence of blood vessels. Hyaluronidase or some closely related enzyme acting on the substrate of chondroitin sulphuric acid may regulate the metabolism of this avascular tissue. There is reason to believe that disturbance of this substrate-enzyme relationship may be the underlying cause of many rheumatoid disorders affecting the cartilage and capsule of joints.* (× 262)

The ability to increase tissue permeability or spreading activity is exhibited by certain types of pathogenic bacteria, particularly pneumococci and haemolytic streptococci, which secrete a spreading factor similar to hyaluronidase.

The permeability of the connective tissues will in part regulate the spread of infection, and control the degree of invading ability of pathogenic organisms. To this extent, therefore, it can determine susceptibility to infection. An animal with a high tissue-permeability should have a higher susceptibility to any infection to which the species is liable, and *vice versa*. For instance, experiment shows that young hosts, with their greater tissue-permeability, develop infection more severely than adults. This is, of course, only one factor in reaction to disease. Under experimental conditions, bacteria and viruses injected with a spreading-factor have an enhanced local primary effect. This is entirely quantitative, and does not promote new conditions or overcome a natural resistance.

Hyaluronic acid, and probably the other mucopolysaccharides, are non-antigenic. When injected into an animal they do not stimulate an immune reaction, i.e. they fail to arouse the normal defence mechanisms, including the production of antibodies, by which the body combats invasion by foreign material. Certain bacteria possess an external covering consisting of these non-antigenic mucopolysaccharides; this gives them a temporary protection from the cellular and chemical reactions of the host. During this period the organisms flourish and thrive, and thus the presence of this mucopolysaccharide capsule greatly increases their virulence.

Although the mucopolysaccharides are non-antigenic, the enzymes such as hyaluronidase are antigenic, and can produce antisera capable of suppressing the *in vivo* and *in vitro* activity of the enzyme. For example, if extracts of bull testes containing large quantities of hyaluronidase are injected into a rabbit, serum can be withdrawn from the rabbit which will suppress the spreading power of the hyaluronidase extracts, and prevent the hydrolysis of hyaluronic acid. These antisera are specific for the source of their production. Some of the therapeutic effects of antisera in general may well be due, at least partly, to their anti-spreading properties. It is also possible that some types of sterility, previously attributed to sperm immunity, may be due to the formation of an antibody active against hyaluronidase. Some of these suspected cases have had their sera tested against bull testes hyaluronidase for increased inhibitory action, with negative results. Considering the species-specificity of hyaluronidase, this is of little significance, and the sera require to be studied against hyaluronidase from human testes.

Hyaluronidase has been used therapeutically to facilitate and hasten the absorption of fluid from the subcutaneous tissue. Normally, there is considerable tissue resistance, which limits the rate at which fluid can be injected. Preliminary injections of hyaluronidase are given to accelerate the absorption of physiological saline or plasma administered hypodermically, when intravenous injection is impossible. The effect of the hyaluronidase lasts for 24 hours.

An administration of 2·5 units of hyaluronidase makes possible the subcutaneous injection of contrast media for X-ray examination of soft parts, such as kidneys, where intravenous injection is contra-indicated or difficult, as it often is in children. There are many further possibilities for the therapeutic use of hyaluronidase.

There is a lack of information regarding the precise chemistry of the mucopolysaccharides, and more knowledge is needed regarding their biological properties. The protein-carbohydrate substances thus provide a wide field of research awaiting the activities of chemists, biochemists, and pathologists.

The chemistry of plant gums and mucilages

E. L. HIRST

The chemistry of gums and mucilages is extremely complicated, as they have high molecular weights and are composed of sugar residues of several different kinds. Their investigation is, however, rewarding, for it bears on one of the most fundamental problems in carbohydrate chemistry, namely the mechanism of the reactions by which the primary products of photosynthesis are transformed into different materials such as other hexoses and pentoses.

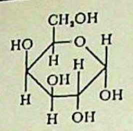
It has been known for many centuries that certain trees, in response to injury to their bark, exude nodules of gummy materials, which have long found a place in the arts and in industry by virtue of their capacity to form viscous pastes, thickening agents, and adhesives. The collection and distribution of these gums is an important branch of commerce, and some idea of the extent of the trade may be gained from the estimate that the yearly sales of gum from *Acacia* trees exceed 20 million kg. In addition, large quantities of gum tragacanth, obtained from *Astragalus* shrubs, of Indian gum from *Sterculia* trees, and of many other gums, are used in industry. These materials serve a wide variety of purposes, including sizing, the printing and finishing of textiles, paper-making, the preparation of water-colours, the manufacture of matches, inks, and pharmaceutical preparations, and in the confectionery trade. They exhibit a wide range of physical and chemical properties, and their scientific investigation has revealed many problems of importance to the biologist and to the chemist.

The mucilages are widely distributed in the plant world, being found as secondary membrane thickening, as intercellular material, and in the cell contents. They occur in the root, bark, cortex, leaves, stalks, flowers, endosperm, and seed coating, and in some bulbs special mucilage cells are present. Between them they play many parts in the life of the plant; they may function as food reserve materials, but in some instances they possess highly specialized functions. It is probable, for instance, that the physical properties of certain mucilages enable them to be used as water reservoirs by plants which live in exceptionally dry conditions, and mucilaginous seed-coatings may function similarly during germination.

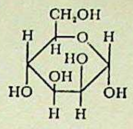
The mucilages are normal products of metabolism, and in this respect they may be contrasted with the plant gums, which are usually formed in response to injury, either accidental, or deliberate as in the slitting of the bark of *Acacia* trees in order to encourage the outpouring of gum. The formation of gummy material under these conditions has been studied in detail, and it appears that starch and other reserve materials undergo transformation into gum, which then exudes as a mobile aqueous solution. This in turn dries to a hard solid, and so forms a protective layer over the injured part. It has been suggested that the gum is actually produced by invading bacteria, but the evidence for this is slight, and the results of recent chemical investigations are opposed to such a view. The plant gums are indeed so highly specific in their chemical structure that some workers believe that a knowledge of the chemical nature of any particular gum would enable the species and perhaps even the variety of the parent plant to be identified.

In their molecular structure, and in their capacity to give viscous solutions, the water-soluble gums closely resemble the plant mucilages, and it is convenient, therefore, to review the properties of both groups of substances despite the wide differences in their biological functions.

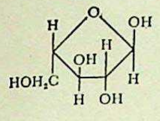
In respect of their chemical structures, the plant gums and mucilages are complex polysaccharides of high molecular weight, and in general they are built up by the union of sugar residues of several different kinds. For instance, the molecule of gum arabic contains *D*-galactose, *L*-rhamnose, *L*-arabinose, and *D*-glucuronic acid. Other sugar residues of frequent occurence in gums and mucilages are *D*-xylose and *D*-mannose. On the whole, *D*-glucuronic acid is characteristic of the gums, while in the mucilages it is replaced by *D*-galacturonic acid, but this rule is not invariable.



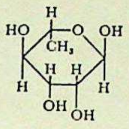
α-*D*-Galactose



α-*D*-Mannose

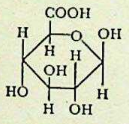


α-*L*-Arabofuranose

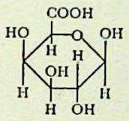


α-*L*-Rhamnose

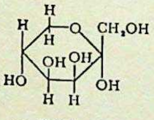
Sometimes very rare sugars are encountered, as, for example, in the gum from the tree *Sterculia setigera*, which contains the ketose sugar *D*-tagatose, this being the only known instance of its occurrence in a natural product. The structures of many of the gums and mucilages are complicated still further by the presence of acetylated and methylated derivatives of the sugar residues. In illustration of this fact, mention may be made of the interesting mucilage obtainable from the bark of the slippery-elm tree (*Ulmus fulva*). Besides *D*-galactose, *D*-galacturonic acid, and *L*-rhamnose, this mucilage contains residues of 3-methyl-*D*-galactose.



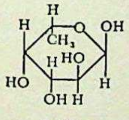
β-*D*-Glucuronic acid



β-*D*-Galacturonic acid



α-*D*-Tagatose



α-*L*-Fucose

TABLE I

Composition of some plant gums and mucilages

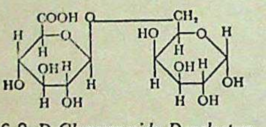
Substance	*Sugar residues present*
Gum arabic	Glu, G, R, A
Cherry gum	Glu, G, M, A, X
Damson gum	Glu, G, M, A, X
Egg plum gum	Glu, G, A, X
Mesquite gum	Glu, G, A and 4-methylglu
Gum tragacanth	Gal, G, F, A, X
Sterculia setigera gum	Gal, G, R, and D-tagatose
Linseed mucilage	Gal, G, R, X
Cress seed mucilage	Gal, G, R, X, A
Seed mucilages from *Plantago psyllium* and *P. fastigiata*	Gal, A, X
Seed mucilage from *Plantago arenaria*	Gal, G, A, X
Mucilage from bark of *Ulmus fulva*	Gal, G, R, and 3-methyl-*D*-galactose
Carragheen	G and sulphate
Fucoidin	F and sulphate
Agar-agar	G, L, and sulphate
Laminarin	*D*-glucose
Alginic acid	*D*-mannuronic acid

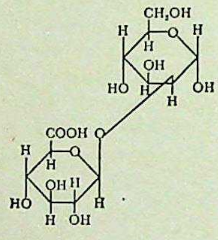
KEY

Glu = *D*-Glucuronic acid
Gal = *D*-Galacturonic acid
G = *D*-Galactopyranose
M = *D*-Mannopyranose
R = *L*-Rhamnopyranose
F = *L*-Fucose
A = *L*-Arabofuranose
X = *D*-Xylopyranose
L = *L*-Galactose

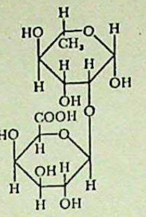
The study of plant gums and mucilages leads us directly to some of the fundamental problems in carbohydrate chemistry, namely, the mechanisms by which the primary products of photosynthesis, which appear to be based on *D*-glucose, are transformed into other hexoses (e.g. *D*-galactose, *D*-mannose); uronic acids (*D*-glucuronic acid, *D*-galacturonic acid); methyl pentoses (*L*-rhamnose, *L*-fucose); and pentose sugars (*D*-xylose, *L*-arabinose, *D*-ribose). It is possible that a detailed structural examination of members of the group may throw light on these difficult questions, and some progress has indeed already been made. For instance, it is now certain that the transformation of *D*-galactose into *L*-arabinose does not take place in the polymeric molecules, despite the close stereochemical relationships of these sugars, and this is probably true also for the transformation of *D*-glucose into *D*-xylose [1]. It remains, however, to be ascertained whether the route favoured is direct enzymic transformation of the monomeric hexose molecules into the corresponding uronic acids and thence into the pentoses, or whether the hexose molecule is first broken down to trioses, as in alcoholic fermentation, with subsequent rebuilding.

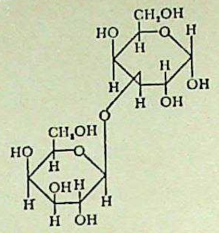
There are therefore many reasons for studying the structure of these complex substances, and there is the additional stimulus that they resemble structurally the bacterial polysaccharides which are so important in chemotherapy. The problems involved, however, are among the most difficult and complicated in the whole field of carbohydrate chemistry. In comparison, the study of cellulose and starch may be considered simple, since these polysaccharides, complex as they are, give rise on hydrolysis to one sugar only. On the other hand, the gums and mucilages usually contain several types of residue, and it is necessary to discover the order in which these occur in the molecule, the problems which arise being similar to those encountered in protein chemistry. Furthermore, a hexose residue may be present in a gum as an α- or β-glycoside, in the pyranose or furanose ring form, and it may be combined through its hydroxyl groups with one, two, three, or four other residues. There are, therefore, scores of structural possibilities for each hexose residue, and the numbers for the pentose and uronic acid residues are almost equally formidable. Fortunately, certain regularities have been observed which introduce some simplification into the problem of assigning a place and structure to each residue, but it is not surprising that in no instance, up to the present, can a unique formula be assigned, although in many cases the broad structural features have been elucidated.

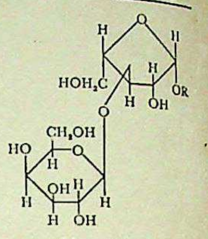

6-β-*D*-*Glucuronosido*-*D*-*galactose*


2-β-*D*-*Glucuronosido*-*D*-*mannose*

In the structural investigation of the gums and mucilages, after preliminary work to ensure the purity and homogeneity of the material under investigation, the polysaccharide is hydrolysed with acid in order to discover the nature of the constituent sugars and the relative proportions in which they are present. In this work, chromatography is proving to be a most valuable aid both for identification and for quantitative determination. Very fortunately, most gums contain groups of residues which are relatively resistant to hydrolysis, and the isolation and identification of these groups provides a first step in the piecing together of the molecular structure. For instance, the aldobiuronic acid 6-β-*D*-glucuronosido-*D*-galactose has been obtained from gum arabic. Damson gum and cherry gum, on the other hand, yield 2-*D*-glucuronosido-*D*-mannose, while the aldobiuronic acid from slippery-elm mucilage and from linseed mucilage is 2-*D*-galacturonosido-*L*-rhamnose. Sometimes disaccharides which resist hydrolysis can be isolated, and further important evidence concerning the linkages between residues is thus provided. Typical examples are 3-*D*-galactosido-*D*-galactose and 3-*D*-galactosido-*L*-arabinose, both of which are obtainable from gum arabic.


2-β-*D*-
Galacturonosido-
L-*rhamnose*


3-β-*D*-
Galactosido-
D-*galactose*


Glycoside of
3-β-*D*-*galactosido*-
L-*arabofuranose*

The arabinose residues are usually present in the labile furanose form and can be removed readily by hydrolysis under mild conditions, leaving a 'degraded' gum which is still a high polymer but of simpler structure. The free hydroxyl groups in this product can be transformed into stable methyl ethers by standard processes, and the fully methylated polysaccharide gives on hydrolysis a complex mixture of partially methylated monoses which can be identified and estimated by chromatographic methods. The free hydroxyl groups in these sugars denote the points through which the various residues are linked together in the polymer, but experiments of this kind give no indication of the order in which they are arranged. Further information is gained by comparing these hydrolysis products with those obtained from the methylated derivative of the original undegraded gum, and this in turn is supplemented by evidence derived from the oxidation of the polysaccharides by per-iodic acid. This reagent attacks any sugar residue containing free hydroxyl groups on contiguous carbon atoms, but leaves untouched all those with linkages such that no glycol groupings are present:

$$\mathrm{R.CHOH\text{-}CHOH\text{-}R'} \rightleftharpoons \mathrm{R.CHO} + \mathrm{R'.CHO}.$$

With these items of information at his disposal it may then be possible for the chemist to formulate the main features of the molecular structure of the gum or mucilage with some precision, while the absolute size of the macromolecule may be investigated by physical methods such as osmotic pressure determinations, sedimentation in the ultracentrifuge, and light-scattering in solution. Should the molecule be long and regular in shape, as for example with alginic and pectic acids, X-ray analysis can give valuable information.

Gum arabic, on which much detailed work has been carried out, may be cited as an example of what has been achieved in structural determination in this group. It has been mentioned already that, by partial hydrolysis of the gum, an aldobiuronic acid and two disaccharides, all of known structure, can be isolated. Furthermore, methylation experiments have shown that the degraded gum is built up of the following residues:

$$\mathrm{G}1\ldots(1\text{ mol.});\ \ldots 6\mathrm{G}1\ldots(5\text{ mols});$$

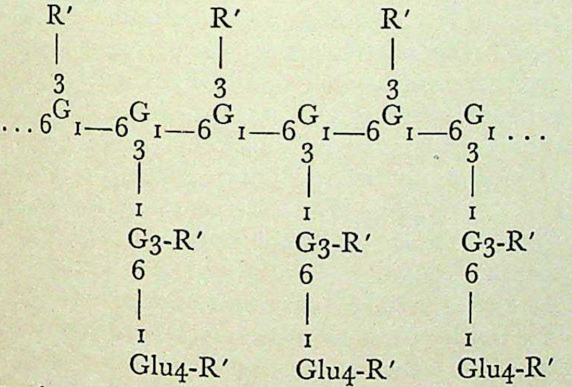
$$\ldots 6\mathrm{G}^{1\ldots}_{3\ldots}(3\text{ mols});\ \mathrm{Glu}\ 1\ldots(3\text{ mols}).$$

(G1 . . . indicates a *D*-galactopyranose linked through its first C atom; 6G1, a similar residue linked through C_1 and C_6, and so on. Glu stands for a *D*-glucuronic acid residue.) In the original gum the residues present are:

$$\mathrm{G}1\ldots;\ \ldots 6\mathrm{G}^{1\ldots}_{3\ldots};\ \mathrm{R}1\ldots;\ \mathrm{A}1\ldots;$$

$$\mathrm{A}^{1\ldots}_{3\ldots};\ \mathrm{Glu}\ 1\ldots;\ \mathrm{Glu}^{\,1\ldots}_{\,4\ldots}.$$

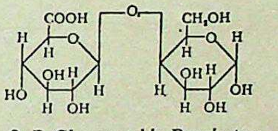
(R = *L*-rhamnopyranose residue, and A = *L*-arabofuranose residue.) Building up from these data, F. Smith [2] was able to advance a possible formula for gum arabic. This, although not the only one which fits the evidence, shows the main features precisely, and the other possible variants differ only in detail.



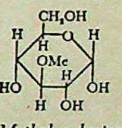
$$\begin{array}{cccccc}
\mathrm{R'} & & \mathrm{R'} & & \mathrm{R'} & \\
| & & | & & | & \\
3 & & 3 & & 3 & \\
\ldots 6\mathrm{G}1- & 6\mathrm{G}1- & 6\mathrm{G}1- & 6\mathrm{G}1- & 6\mathrm{G}1- & 6\mathrm{G}1\ldots \\
 & 3 & & 3 & & 3 \\
 & | & & | & & | \\
 & 1 & & 1 & & 1 \\
 & \mathrm{G}3\text{-}\mathrm{R'} & & \mathrm{G}3\text{-}\mathrm{R'} & & \mathrm{G}3\text{-}\mathrm{R'} \\
 & 6 & & 6 & & 6 \\
 & | & & | & & | \\
 & 1 & & 1 & & 1 \\
 & \mathrm{Glu}4\text{-}\mathrm{R'} & & \mathrm{Glu}4\text{-}\mathrm{R'} & & \mathrm{Glu}4\text{-}\mathrm{R'}
\end{array}$$

One of the possible formulae for gum arabic. G = D-*galactose residue; Glu =* D-*glucuronic acid residue; R′ =* L-*rhamnose residue, or* L-*arabofuranose residue, or* 3-β-D-*galactosido*-L-*arabofuranose residue.*

It will be seen that the structure consists of a continuous backbone of *D*-galactose residues, to which are attached numerous side chains containing other galactose residues together with the rhamnose, arabinose, and glucuronic acid residues. It is at present premature to generalize in this field, but there is some evidence that this backbone of galactose residues is of wide occurrence. It seems to be present also in damson gum [3], which is related to gum arabic in its general architecture but differs from it in containing *D*-xylose and *D*-mannose but no *L*-rhamnose. There are, however, important structural differences, in that the aldobiuronic acid from damson gum, 2-*D*-glucuronosido-*D*-mannose, possesses a 1,2 linkage. Examination of the methylated gum has revealed the presence of at least ten different kinds of sugar residue, and, although the main feature again appears to be a chain of *D*-galactose residues, it is not surprising that no precise molecular structure can yet be put forward. Cherry gum [3] shows a close resemblance to damson gum but is even more complex. It gives rise to the same aldobiuronic acid, but as compared with damson gum it contains more *D*-xylose and *L*-arabinose residues. Rather unexpectedly, it appears that the gum from the egg-plum tree [4] is structurally more closely related to gum arabic, since the aldobiuronic acid derived from it is identical with the corresponding material from gum arabic. A preliminary examination of the gums from lemon and grape-fruit trees shows that in these yet another type of aldobiuronic acid is present, namely 4-*D*-glucuronosido-*D*-galactose, and the diversity of structure is further exemplified by mesquite (*Prosopis juliflora*) gum [5], which gives two such acids, 4-β-*D*-glucuronosido-*D*-galactose and a monomethyl ether of 6-β-*D*-glucuronosido-*D*-galactose.



4-β-D-Glucuronosido-D-galactose



3-Methyl galactose

The industrially important gum tragacanth is a mixture of a neutral polysaccharide, possibly an araban, and an acidic portion which resembles the mucilages in containing *D*-galacturonic acid residues in place of the glucuronic acid commonly found in gums. Methylation experiments [6] have revealed the general structure, which is built up of residues of:

$$\mathrm{F}1\ldots;\ \mathrm{X}1\ldots;\ \mathrm{X}^{1\ldots}_{2\ldots};\ \mathrm{Gal}^{\,1\ldots}_{\,4\ldots};$$

together with some triply bound galacturonic residues. (F = *L*-fucose, X = *D*-xylose, Gal = *D*-galacturonic acid.)

The plant mucilages possess molecular structures of the same general type. For convenience, they may be classified into three main groups: (*a*) neutral polysaccharides of high molecular weight containing one or more kinds of sugar residues, but no uronic acid; (*b*) acidic polysaccharides resembling the gums but usually with

D-galacturonic acid as the acidic residue; and (*c*) polysaccharides, frequently present in algae, of complex structure and high molecular weight, containing sulphate ester groupings.

Large numbers of these have been isolated, and they are clearly of great biological interest and importance, but comparatively little is yet known of the detailed structure of any of them. In this article, it will be possible only to mention briefly one or two typical examples. One of the simplest is the salep mannan obtained from the tubers of one of the *Orchidaceae*. This appears to be a linear polymer of 1,4-linked mannopyranose residues:

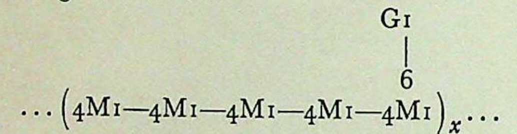
$$(\ldots 4\text{—}1\mathrm{M}4\text{—}1\mathrm{M}4\ldots).$$

Gum gatto [7] (carob seed mucilage, probably very similar to locust bean mucilage) is more complex, being composed of the following residues:

$$\mathrm{G}1\ldots(1\text{ part}),\ \mathrm{M}^{1\cdots}_{4\cdots}\,(4\text{ parts}),$$

$$\text{and}\ldots 6\mathrm{M}^{1\cdots}_{4\cdots}\,(1\text{ part}).$$

One of the possible molecular structures for this mucilage is therefore:



$$\ldots\left(4\mathrm{M}1\text{—}4\mathrm{M}1\text{—}4\mathrm{M}1\text{—}4\mathrm{M}1\text{—}4\overset{\overset{\mathrm{G}1}{|}}{\overset{6}{\mathrm{M}}}1\right)_x\ldots$$

Lucerne seed mucilage also consists of *D*-galactose and *D*-mannose residues, but its structure is more complicated, since two types of galactose residue are present, and the mucilage differs from gum gatto in that no 1,4-linked mannose residues are present. In many other of the neutral mucilages *L*-arabinose occurs in large proportions, together with *D*-galactose.

Still greater complexity is encountered with the mucilages of class (*b*), some of which have been examined in considerable detail. Examples of great interest are to be found in the seed mucilages of various species of *Plantago*. These all contain *D*-galacturonic acid residues, but display remarkable differences in detailed structure from species to species. The mucilage from *P. arenaria* contains *D*-xylose, *D*-galactose, and *L*-arabinose; that from *P. lanceolata*, *D*-galactose, *L*-rhamnose, and *D*-xylose; and those from *P. psyllium* and *P. fastigiata* L-arabinose and *D*-galactose. Methylation experiments conducted with the mucilages from *P. lanceolata* and *P. arenaria* have revealed a bewildering complexity of structure, with the xylose residues acting as branching points in a highly ramified molecule [8].

Some mucilages in this group, for instance those from quince seed and white-mustard seed, occur in the plant in combination with cellulose, the complex being water-soluble. Linseed mucilage yields on partial hydrolysis the aldobiuronic acid 2-*D*-galacturonosido-*L*-rhamnose, which occurs also in the gum from *Sterculia setigera* and in the mucilage from the bark of *Ulmus fulva*. *Ulmus fulva* mucilage has been studied by the methylation method, and it is known that residues of

$$\mathrm{Gal}\ 1\ldots;\ \mathrm{Gal}^{\,1\cdots}_{\,4\cdots};\ \mathrm{G}1\ldots;\ \mathrm{G}^{\,1\cdots}_{\,3\cdots};$$

$$\mathrm{G}^{1\cdots}_{4\cdots};\ \mathrm{R}^{1\cdots}_{2\cdots};\ \overset{1\cdots}{\underset{3\cdots}{\mathrm{R}2\ldots}}$$

are present in addition to residues of 3-methyl galactose, but no detailed structure can yet be assigned [9].

Problems of special difficulty abound in the study of the algal mucilages, which contain sulphate ester groupings. The best known of these mucilages contain sulphated galactose residues (agar-agar from *Gelidium* and *Gracilara* spp.; carragheen from *Chondrus crispus*), or sulphated fucose residues (e.g. fucoidin from *Laminaria* and *Fucus* spp.). There is reason to suppose that in carragheen the sulphuric acid residue is linked to C_4 of a galactose residue, and that the essential feature of the molecular structure is a backbone of 1,3-linked *D*-galactose residues, similar to that found in the plant gums [10]. The mucilage from the seaweed *Gigartina stellata* probably contains a similar galactose backbone, with attached side chains [11]. Agar-agar is known to contain 1,3-linked *D*-galactose residues, but on hydrolysis this substance gives rise also to *L*-galactose, and from fully methylated agar-agar it is possible to obtain derivatives of 3:6-anhydro-*L*-galactose. The structure is highly complicated, and despite intensive work no structural formula can yet be advanced with certainty [12].

As a final example we select the interesting and unusual mucilage laminarin [13], which occurs in *Laminaria* spp. together with alginic acid and mannitol. It consists solely of *D*-glucose residues, some of them possibly sulphated, and it is of interest to note that here again we encounter the 1,3-linkages which are so frequently present in algal polysaccharides. The main features of the structure are represented by the formula:

$$\ldots 3\mathrm{G}^*1\text{—}3\mathrm{G}^*1\text{—}3\mathrm{G}^*1\ldots$$

($G^* = D$-glucopyranose residue.)

It is remarkable that the property of gumminess should be shared by so many substances of diverse chemical structure, and at present only a partial explanation of this can be given. It is probable that if a water-soluble substance is to be capable of acting in this way its molecule must contain hydroxyl groups capable of forming hydrogen bonds with water molecules, while at the same time the geometry of the molecules must be such that these cannot readily align themselves closely and regularly with each other. When this can happen, as in the case of the unbranched thread-like molecules of cellulose, intermolecular hydrogen bonding results in the formation of insoluble material which can be dispersed only by a solvent having a still stronger affinity for the hydroxyl groups. It is known, however, that a disturbance of the geometrical arrangement in cellulose, occasioned by the introduction of a small percentage of bulky substituent groups, will result in the formation of water-soluble derivatives. We have seen that most of the gums and mucilages possess highly branched structures, the hydroxyl groups in which are ideally placed for attachment to water molecules, and even in the simpler cases there is no possibility of that compact geometrical alignment with intermolecular hydrogen bonding such as occurs in cellulose. In consequence, the gums remain heavily hydrated even in the most concentrated solutions. Nevertheless, there must be some intermolecular hydrogen bonding between the gum molecules themselves—not very pronounced in highly dilute solution, but tending to give a structure of increasing rigidity as the water is removed—and it is possible that an explanation of the characteristic physical properties of the gums and mucilages is to be found in the delicate interplay between these two opposed reactions.

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Book reviews

SCIENCE AND LIFE

Man is a Microcosm, *by J. A. V. Butler. Pp.* 151, *with line and half-tone illustrations. Macmillan and Company Limited, London.* 1950. 10*s.* 6*d. net.*

Dr Butler has written an admirably clear, balanced, and up-to-date account of the modern application of physics and chemistry to the life of organisms and man, and its implications for our view of man. Beginning with the chemistry of proteins, he proceeds to discuss enzymes, vitamins, hormones, viruses, and genes, and outlines their roles in the maintenance and control of the living organism, in development and growth, in reproduction, and in the action of muscles, nerves, and brain. He reviews our meagre knowledge of the origin of life, throws much light on the fashionable analogy between the brain and a calculating machine, and concludes with a chapter on the stature of man.

Dr Butler's aim is to suggest some notion of the great complexity and ingenuity exhibited in the working of living things as they are now understood, in order to correct the view derived (illogically) from nineteenth-century physics, that man is an insignificant being because he lives on a planet which is not astronomically important, still less unique, and is a mere speck in the immensity of space. Dr Butler suggests that 'the balance may be redressed by the complementary studies of living structures, which, by revealing a world as rich in texture as the other is vast, may make men feel again that they are not out of keeping with the splendour of their setting.' This is a most stimulating and honest book, and will be useful both to the scientist and to the general reader.

E. F. CALDIN

A CENTURY OF TECHNOLOGY

A Century of Technology, *edited by Percy Dunsheath. Pp.* 346, *with twenty illustrations and five line diagrams. Hutchinson's Scientific and Technical Publications, London.* 1951. 15*s. net.*

In the last hundred years, science has made a greater impact on civilization than during any previous century. Not only have investigation and research been very much more active; in addition, we have learned to make vastly greater practical use of the discoveries we have made. To describe technological progress since 1851 is a Herculean task. In *A Century of Technology* this has been attempted by eighteen specialist contributors under the editorship of Dr Percy Dunsheath. The result is a book which, in providing a bird's-eye view of this exciting century of science, must prove invaluable to all scientists and technicians.

It is unavoidable that in a survey of this sort many things should be omitted or given but scant attention. The development of radio, for example, and the lively new field of synthetic fibres, are two subjects which deserve to be treated more fully than they are. Such criticisms are, however, inevitable in discussing a survey of this type. A quart can never be persuaded into a pint pot without something being spilled.

J. G. COOK

PHYSICAL ORGANIC CHEMISTRY

Physical Aspects of Organic Chemistry (*fourth edition*), *by W. A. Waters. Pp.* xii + 539. *Routledge and Kegan Paul, London.* 1950. 35*s. net.*

Since it first appeared some fifteen years ago this book has been recognized as one of the best surveys of the theory of organic chemistry. The intervening years have seen great changes, and the basic ideas of chemical theory have been placed upon a wider and firmer foundation. The newer quantum theories, the concept of resonance, the unravelling of the intricacies of molecular structure, and many other developments have resulted in the emergence of a clearer picture of the fundamental mechanism of chemical change. It is in terms of these new ideas that the principles of organic reactions should be formulated. The fusion of the different concepts of the physical and organic chemist is difficult, since they look at reactions from a different viewpoint. In the present edition, which has been largely rewritten, Dr Waters has successfully achieved this end, and has given a unified and comprehensive summary of a very wide subject. His viewpoint is essentially that of the organic chemist, and he develops his treatment from the historical aspect. The old and newer ideas are given equal prominence, and the difficulties of terminology which have arisen with the growth of the subject, and which have led to much confusion, are clearly and concisely explained. The basic principles of modern theoretical organic chemistry are formulated, and applied to the many types of organic reactions. These ideas are developed in chapters which cover free radical reactions, catalysis, ionization and ionic reactions, strength of acids, ester hydrolysis and esterification, substitution reactions, molecular rearrangements, ionotropic change, and reaction of conjugated systems, with two final chapters on aromatic behaviour. The volume serves the dual purpose of an up-to-date review and an advanced textbook, and should be valuable to both the student and advanced worker.

C. E. H. BAWN

PRACTICAL SPECTROSCOPY

Practical Spectroscopy, *by G. R. Harrison, R. C. Lord, and J. R. Loofbourow. Pp. xiv* + 605, *with numerous half-tone and line diagrams. Blackie and Son Limited, London.* 1949. 35*s. net.*

The 600 pages of this book give a comprehensive account of almost every aspect of modern practical spectroscopy. Among the many subjects dealt with are spectrograph types and mountings; conditions of illumination; characteristics of various sources; technique of photography; principles of quantitative intensity; measurements by photographic, photoelectric, and bolometric means; absorption spectroscopy; spectroscopy of the infra-red and vacuum ultra-violet; Raman effect; and interferometry. There are chapters on qualitative and quantitative spectrochemical analysis, and on the theory of atomic and molecular spectra. The book is extremely clearly and well written, so well indeed that it makes the subject look perhaps a little too easy, and as though there are few problems left to solve. In the sections on visible and ultra-violet emission spectra the emphasis is on atomic spectra, and the existence of molecular emission spectra is largely ignored. The section on discharge tubes and sources for band emission spectra is relatively weak, and a description of modern low-voltage hydrogen lamps would be welcome. However, these are details, and the treatment is so full that it is easier to list what it omits than what it includes. This most valuable, indeed indispensable, work originates from the Massachusetts Institute of Technology, which has done so much to develop spectroscopy, and the combination of a physicist, a chemist, and a biophysicist has produced a balanced, and yet smooth, account of the whole subject.

A. G. GAYDON

BORON TRIFLUORIDE

Boron Trifluoride and its Derivatives, *by H. S. Booth and D. R. Martin. Pp.* 315, *with several line diagrams. John Wiley and Sons, New York; Chapman and Hall Limited, London.* 1949. 40*s. net.*

The usefulness of boron trifluoride in organic chemistry as a catalyst for alkylation, polymerization, and isomerization reactions has brought this compound very much to the fore in recent years. It has, indeed, been produced commercially since 1936, and has a well-established place both in research and in industry. The authors of this monograph have collected and classified the information on boron trifluoride and its derivatives which has accumulated since the compound was discovered in the early part of the last century. They deal in turn with its preparation and physical and chemical properties, the co-ordination compounds, the fluoboric acids and their salts, and the catalytic properties. The two final chapters are on the analysis of boron trifluoride and its derivatives, and on its practical handling. The bibliography contains almost a thousand references, among which are many from the patent literature.

The most useful section of the book is that on catalysis by boron trifluoride and its derivatives. The information given is systematically arranged, and enables the reader to follow the literature on a particular topic with great ease. The incompleteness of our understanding of the structure and mode of action of the organic derivatives is all too clear. Unfortunately, the authors give little assistance in this respect. For the most part their approach is non-critical, and they are often contented to state the bare facts much as they would be recorded in *Chemical Abstracts*. They also fail to come to grips with the very difficult problems of nomenclature which are raised. In spite of these limitations, however, their work can hardly fail to create interest in the subject. Not only in the organic, but also in the inorganic and physicochemical fields, there are many problems which await further study and elucidation. So complete a review of the present position will stimulate further progress.

H. J. EMELÉUS

ELEMENTARY CHEMISTRY

College Chemistry, *by Linus Pauling. Pp.* 705, *with two coloured plates and many other illustrations. W. H. Freeman and Company, San Francisco, California.* 1950. 34*s. net.*

This is a delightful book, designed to lead a complete beginner step by step logically to a sound understanding of the fundamentals of general chemistry. The approach to the subject is the modern one, and follows much the same lines as the author's *General Chemistry* but proceeds at a rather gentler pace. The nature of atoms and the molecular structure of matter are introduced early, and descriptive chemistry is introduced gradually against this background and alongside a discussion of theoretical principles. The selection and presentation of subject-matter, which ranges over a very wide field, make reading and assimilation easy; in fact, the text really teaches the subject-matter. Each chapter concludes with a summary of the concepts, facts, and terms which have been introduced, followed by the usual exercises and questions.

The book is well printed and plentifully illustrated with attractive diagrams and perspective drawings. It is broader in its concept, and in places less detailed, than demanded by some English examinations, but even in this connection it can be recommended to students reading for the General Certificate (Advanced and Scholarship papers) and for the Intermediate B.Sc. It gives an unusually clear picture of the subject as a whole as well as illuminating explanations of some theoretical topics; even quite advanced students will find in it much that is of advantage.

F. FAIRBROTHER

RADIATIVE TRANSFER

Radiative Transfer, *by S. Chandrasekhar. Pp. xiv* + 393, *with several line diagrams. Clarendon Press, Oxford.* 1950. 35*s. net.*

A typical problem in radiative transfer is to calculate the properties of the diffusely reflected and transmitted radiation if radiation is incident in a given direction on a layer of scattering material. In each elementary scattering process the amount of radiation scattered from one direction to another may vary with the angle between these directions, and with the state of polarization of the radiation. The results may be obtained as the solution of (*a*) integro-differential equations of transfer, or (*b*) integral equations which are the mathematical expression of principles of invariance, arrived at by regarding any single layer of material as equivalent to two adjacent layers.

Professor Chandrasekhar is a leading contributor to the mathematical formulation of such problems, and to the origination and development of methods of solution. The latter include his exploitation of 'Gauss sums' to replace integrals, and his investigation of a new class of non-linear integral equations. This book is largely an account of his own recent work, illustrated by applications to problems of the sunlit sky and of planetary and stellar atmospheres. Its importance for problems of neutron-diffusion is mentioned but not illustrated. The author aims at a unified treatment, possessing a sufficient degree of accuracy, of a comprehensive class of problems. His book revolutionizes the outlook upon a great part of the subject and marks an epoch in its development.

W. H. McCREA

THE ACTINOMYCETES

The Actinomycetes, *by Selman A. Waksman. Pp. xviii* + 230, *with* 36 *half-tones and* 9 *line drawings. Chronica Botanica Limited, Waltham, Mass.* 1950. $5 *net.*

When Dr Waksman isolated the series of antibiotics exemplified by streptomycin he brought the actinomycetes at one bound out of obscurity into prominence. Today the culture of these micro-organisms is an industry, and a knowledge of their morphology, classification, and nutritional requirements has become of far more than academic importance. In this book, however, Dr Waksman lays no undue stress on antibiotic production, which receives a brief but masterly survey in the 26 pages of Chapter 7. The preceding chapters give a balanced review of the taxonomy, morphology, and metabolism of the group, and a more detailed account of seven selected species. A further 40 pages sum up the literature on the distribution and function of the actinomycetes in nature, and on the part they play in inducing plant and animal diseases.

The production has occasional irritations for the reader, such as the unnecessarily small type for the table headings, and the use of an eye-tiring glossy paper not justified by the quality of the photographs printed with the text. These are, however, minor flaws in a volume which on every page shows evidence of having been written by an outstanding participant in the study of the actinomycetes.

R. W. MARSH

DETECTION OF ATOMIC PARTICLES

Ionization Chambers and Counters, *by D. H. Wilkinson. Pp.* 266, *with various line diagrams. Cambridge University Press, London.* 1950. 25*s. net.*

Dr Wilkinson's book is another notable addition to the already long list of Cambridge monographs. It is a book for the specialist but one which every nuclear physicist should possess, covering as it does a field on which so much has been written in research periodicals but to which so few books have been devoted.

The first four chapters give a lucid description of the fundamental theory involved in the use of ionization chambers, proportional counters, and Geiger counters. The next three chapters deal with the more practical aspects of each of these devices individually, and the last chapter very briefly describes the statistics of the recording and counting of charged particles. In general, the main emphasis is on proportional and Geiger counters, and an excellent review of the present state of the theory of their modes of action is given, as well as many practical tips for their operation.

The style of writing is clear, if at times a little robust. In addition, the reviewer hopes that, when the second edition appears, the excellent and most useful final chapter may perhaps be somewhat lengthened. The list of references is comprehensive, and drawn from an unusually wide field.

This volume is rather more expensive than its companions in the series, but it should nevertheless have a wide sale.

C. L. SMITH

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Was born in 1882 and was educated at Harvard University. He has been a member of the physics department in that university since 1908 and Hollis professor of physics since 1926. His principal experimental work has been the measurement of various physical effects of high hydrostatic pressures. He has also written on thermodynamics and the foundations of physics. He was awarded the Nobel Prize for physics in 1946.

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ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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British contributions to science, 1851–1951

PART ONE

Science is international and of all time, and a review of British science in the last hundred years must therefore be in a double sense misrepresentative. If this is recognized, however, it may be not wholly insignificant. No one is so catholic as not to be specially influenced by the circumstances of his own time and place, and we may therefore expect some sort of unity, loose and obscure though it may be, in the contributions made by British workers to the general movement of science since the Great Exhibition in London in 1851. No attempt is made here to recognize and formulate that unity, but the more discerning reader may perhaps do so for himself.

In observational astronomy, the lead that Britain had established through the work of the Herschels and Lord Rosse had come to an end by the middle of the nineteenth century; it was soon to pass to America, where it still remains. This applies more particularly to telescopic observation. On the spectroscopic side, Huggins and Lockyer were pioneers in what has become the dominant part of astronomy, namely astrophysics. Huggins began the investigation of radial velocities of the heavenly bodies, which is still our chief source of information concerning the structure and mechanical behaviour of the universe. His elucidation of the nature of nebular matter, soon to be followed by Lockyer's similar interpretation of solar prominences, inaugurated the now conventional mode of attack on the problem of the chemical constitution of the universe. Furthermore, Lockyer's daring—and for long unaccepted—dissociation hypothesis, according to which atoms were broken up into simpler constituents in the hotter stars, paved the way for the yet more successful attack on the problem of the physical conditions obtaining throughout the universe, as well as for the atomic theories and discoveries which simultaneously revolutionized physics. When the character of Lockyer's dissociation idea was more clearly understood, the theoretical interpretation of his work, first by Saha and then by R. H. Fowler and Milne, led directly to our present knowledge of the structure of stellar atmospheres. As the further development of spectroscopic astronomy—its importance having thus become recognized—passed to regions better equipped for the purpose by nature and the munificence of man, Britain, through the work of Eddington, set afoot another of the major adventures of astronomy, namely the theoretical investigation of the conditions in the interiors of stars and in interstellar space.

At the time of the Great Exhibition the doctrine of energy was just becoming established in physics: one of the supreme generalizations of science. Its conservation—the subject of the first law of thermodynamics—was established largely through the work of Joule, and its degradation—the subject of the second law—largely through the work of William Thomson (Lord Kelvin). The application of these laws to an assumed molecular structure of matter owed as much to Clerk Maxwell as to anyone, and his investigations, with those of Boltzmann and, in a slightly different form, of Gibbs, remain the basis of the classical kinetic theory of gases. Maxwell and Larmor's contributions to electro-magnetic theory also remain the basis of modern ideas on that subject. They were essentially the mathematical expression of the earlier views of Faraday, and among their outstanding consequences, which Maxwell himself immediately realized, is the famous electro-magnetic theory of light, which united optics and electro-magnetism into a single subject. Maxwell was thus one of the founders of both the particle and the field concepts of physical theory, the interrelationships of which have since formed so puzzling a part of modern science. His concept of indestructible molecules, however, which was challenged by Lockyer's dissociation hypothesis, was profoundly modified at the end of the nineteenth century by J. J. Thomson's discovery of the electron.

The new situation, thus created almost simultaneously with the discovery in continental Europe of radioactivity and X-rays, was exploited to the full by Rutherford. By highly original methods, and inspired by highly original conceptions, he outlined the solar system model of the atom which led first, through his pupils Moseley and Bohr, to the understanding of the outer structure of atoms and the mechanism of radiation, and later, through his own work and that of an army of distinguished students, to what we now know of the atomic nucleus. In its early stages Bohr's theory of radiation was nourished and eventually brought to maturity largely through the experimental work of A. Fowler, a pupil of Lockyer's, and it may truly be said to be the valid form of the dissociation hypothesis. Nuclear work is at the moment the chief centre of interest in physics, but what will come of it can be only conjectural.

Chemistry was ahead of physics in conceiving of the discrete structure of matter, and it was not until late in the nineteenth century that the true relations between Dalton's atoms and Maxwell's molecules were clearly seen. Thereafter, physical investigations amplified the chemist's periodic table in a manner unthought of by Newlands, who first pointed out the relation between the properties and the atomic weights of the elements, and by Mendelejeff, who, by his fuller treatment of it, secured general acceptance for the idea. It was thus fitting that the discovery of a whole new family of elements, which became known as the rare gases, should have been inaugurated by the joint work of a physicist, Lord Rayleigh, and a chemist, Sir William Ramsay. These gases—and especially helium, which was first discovered in the Sun by Lockyer and named by him as a new element twenty-seven years before being found on the Earth—have played an important part in clarifying the true relations between the elements. Early work on the disintegration of atoms gave Soddy the idea of isotopes, i.e. elements occupying the same place in the periodic table because of their identical chemical properties, but differing in atomic weight. Aston's perfected form of J. J. Thomson's early mass spectrograph was instrumental in revealing a large number of isotopes, and in transforming Prout's hypothesis—that the weights of all atoms are multiples of a single unit weight—from a speculation into an approximately correct form of an established fact. Space allows only the barest mention of the pioneer work of Sir William and Sir Lawrence Bragg in the determination of crystal structure by means of X-rays.

It is not inaccurate to say that in 1851 there was no general guiding conception in biology: the subject was approximately in the stage reached by astronomy when the first star maps were being constructed. The data were, of course, far more complex, and for their complete description were at least as dependent on the microscope as astronomy was on the telescope. The conception of evolution through natural selection, which we owe to Darwin and Russel Wallace and which came prominently before the scientific world and the general public through the publication of Darwin's *Origin of Species* in 1859, thus laid the foundation of generalized biology. Not only did it put forward the ancestry of individual species as a subject for scientific investigation, but it brought together previously independent lines of research in anthropology, ethnology, geology, palaeontology, physiology, anatomy, and other sciences, and showed them as contributing to an understanding of one grand process. The other great biological generalization—that concerned with the mechanism of heredity—as well as the discovery of the occurrence and importance of mutations, we owe to continental workers, though British contributions to its later development by Bateson and his school have been prominent. Mention of heredity inevitably brings to mind the original and indispensable work of Galton, who, though he reached no wide generalization in the subject and in fact did not aim at doing so, nevertheless facilitated advances of equal importance by the introduction and development of new techniques, particularly in the almost untouched field of the inheritance of mental characteristics. His most distinguished follower, Karl Pearson, not only carried his work further forward but contributed to the understanding of the fundamental meaning of scientific investigation.

As science advances, it becomes increasingly a matter of extending investigation into details, leading at irregular intervals to comprehensive co-ordinating conceptions. The latter stand out as the landmarks of progress, but the former are similarly indispensable and may demand abilities of different but scarcely lower quality. One cannot begin to mention the fundamental work on which later generations will build without realizing the arbitrariness of the choice that must inevitably be made. Nevertheless, in spite of his cherished presence still in our midst, it is impossible to omit a reference to Sir Charles Sherrington's outstanding work on the integrative action of the nervous system, which is unmistakably marked for endurance. Gowland Hopkins' discovery of the importance of the accessory food factors known as vitamins and Bayliss's discovery of hormones, are also events of great and permanent value. Work of this kind is unquestionably in the direct line of descent from that of the earlier seekers after truth for its own sake, but in biology particularly it is becoming more and more difficult to isolate basic contributions to science from their applications to the prevention and treatment of disease. Here again it is impossible justly to order events according to their importance. Lister's method of antiseptic surgery and Ross's discovery of the transmission of malaria by a particular species of mosquito are neither of them of prime importance in the progress of pure science, yet who can estimate their value as applications of science to the relief of man's estate?

The origin of the solar system

SIR HAROLD SPENCER JONES

The problem of the origin of the solar system is the most difficult in cosmogony and has been an intellectual challenge for some two and a half centuries. The very plausible theories put forward by such eminent men as Kant, Laplace, Fouché, Jeans and Jeffreys, Lyttleton, Hoyle, and Alfvén, have all in time had serious doubts cast upon them. At present there is great interest in Weizsäcker's theory, which is in some respects related to that put forward by Kant in 1755 and regards the solar system as resulting by evolution from a primordium rather than by the cataclysmic intervention of some other celestial body.

The solar system shows so many regularities, both in its dynamical and in its physical properties, that it cannot have been formed by chance. This fact was emphasized first by Laplace, who, in the *Exposition du Système du Monde* (1796), pointed out that the planets move round the Sun in the same direction and nearly in the same plane; that the satellites move round their parent planets in this same direction and nearly in the same plane as the planets; that the Sun, the planets, and their satellites rotate in the same sense as that of their revolution; and that the inclinations of their equators to their orbits are small. Laplace estimated that the odds against these regularities being due to chance was more than two hundred thousand milliards (2×10^{14}) to one.

Since the time of Laplace the known solar system has been enlarged by the discovery of two planets, of fifteen satellites, and of more than 1500 asteroids. With a few exceptions, these additional members show the same regularities. A further significant feature of the solar system, which was not mentioned by Laplace, is that the eccentricities of the orbits of the planets and of their satellites are, with few exceptions, small. No theory of the origin of the solar system can be considered as satisfactory unless it is able to account for these features of the system.

There are other characteristics of the system which must be mentioned. The planets can be divided into two groups having important differences. The inner planets have relatively small masses, high densities, slow rotations, and few satellites. The outer planets have large masses, low densities, rapid rotations, and many satellites. Pluto, the outermost known planet, is anomalous in many respects.

A curious empirical law connecting the mean distances of the planets from the Sun was formulated by Bode in 1772. Bode's law can be expressed in the form:

$$r_n = a + b \cdot 2^n,$$

in which r_n denotes the distance of the nth planet from the Sun, and a and b are constants. It requires a planet between Mars and Jupiter which, at the time it was formulated, was missing; the subsequent discovery of the asteroids, which are possibly the remnants of a disrupted planet, can be regarded as having filled the gap. Uranus, Neptune, and Pluto were not discovered until after 1772. Though Adams and Leverrier both used Bode's law in predicting the position of the unknown planet assumed to be responsible for the perturbations of Uranus, Neptune does not fit the law very well, and Pluto does not fit it at all. A better fit for the outer planets can be obtained, however, by an adjustment of the constants of the formula. The relative distances from their parent planet of the satellites of Jupiter, Saturn, and Uranus can be fitted fairly well to a similar law. This type of distance-law may therefore be of significance for the mode of formation of the solar system.

The distribution of angular momentum in the solar system is peculiar. The Sun, which has more than 99 per cent. of the mass of the system, contributes through its rotation a mere two per cent. to the total angular momentum; the major planets, on the other hand, though they contain less than one-seventh of one per cent. of the total mass, contribute in their orbital motions almost the whole (98 per cent.) of the angular momentum of the system. The rotations of the planets and the motions of their satellites contribute a negligible amount. The satellite systems of the major planets show quite a different distribution of angular momentum, the rotation of the central body contributing much the greater part. In the solar system the puzzle is not why the planets have so much angular momentum, but why the Sun has so little.

Very many different theories have been proposed, for it has proved to be the most difficult problem in cosmogony. The various theories can be divided into two groups, the monistic and the dualistic. The monistic theories suppose that the system was formed by a process of evolution from a primordial system, without interaction from any outside forces; the dualistic theories suppose that it was formed through the intervention of some other celestial body, usually involving a cataclysmic action.

The earliest theory worthy of mention was proposed in 1755 by Immanuel Kant in his *Allgemeine Naturgeschichte und Theorie des Himmels*. He supposed that the Sun was originally at the centre of a nebula that was in rotation round the Sun under its gravitational attraction. Collisions between the separate particles caused the nebula to flatten out into a disk. The matter in this disk gradually collected round the denser portions, forming a number of smaller systems, each in rotation. Kant supposed that in each of these sub-systems a similar evolution took place, either a planet or a planet and satellite system being formed. The larger the sub-system, the greater its gravitational attraction and the larger the number of satellites. The theory gave a plausible explanation of the common orbital plane and of the common direction of rotation and revolution, but it is unable to account for the distribution of angular momentum. Kant was, of course, unaware of this difficulty. The theory is of interest because, as we shall see, it has been revived with modifications in recent years.

Laplace, who did not know of Kant's theory, proposed a somewhat different theory in his *Exposition du Système du Monde*. He supposed that the Sun was originally surrounded by a hot gaseous atmosphere, which gradually cooled, contracting at the same time. The rate of rotation increased as the contraction progressed, until eventually the centrifugal force at the equator became greater than the gravitational force, when a ring of matter was thrown off. The process was repeated, a succession of rings being formed. The central mass eventually became our present Sun. Each ring was supposed to condense into a smaller nebula, in which the process was repeated, giving rise to the planet and satellite systems.

Laplace's theory is untenable for several reasons. Clerk Maxwell in 1859 showed that a ring, such as would have been thrown off by the contracting mass, would not coalesce to form a single body, but that its final stable state would consist of a large number of small bodies; a swarm of asteroids might, in fact, be produced in such a way, but not a planet. The theory breaks down also over the angular momentum difficulty. If the whole of the angular momentum of the solar system were concentrated in the Sun, its period of rotation, instead of being 27 days as at present, would be about 12 hours; the centrifugal force at its equator would even then be only 5 per cent. of the force of gravity, so that rings of matter could not have been thrown off in the way Laplace had supposed.

The angular momentum difficulty was first emphasized by Fouché in 1884. It is inherent in any monistic theory. It was natural, therefore, to inquire whether a workable theory could be constructed on the assumption that the angular momentum of the system had at some time in the past been changed by the intervention of an outside body. Chamberlin and Moulton in 1910 suggested that another star in its passage through space had chanced to pass close to the Sun. The two bodies, mutually attracted by their gravitational pull, swung round one another in hyperbolic orbits, their closest approach being a few solar diameters, and then separated. The tidal action of the passing star raised an enormous wave on the Sun, which, aided by the expansion of the hot compressed solar gases, produced a succession of huge eruptions. The ejected material was dragged round by the gravitational pull of the passing star, so that it was caused to move in eccentric orbits round the Sun and more or less in the same plane. Chamberlin and Moulton supposed that this matter would condense into liquid droplets or planetesimals, which would quickly solidify, and that the larger particles would grow, at first by other particles sticking to them when they collided, and then by accretion due to gravitational attraction. The residual matter would form a resisting medium, which would gradually reduce the eccentricities of the orbits to small values. Some of the matter would escape from the system; some would fall back on the Sun and give it a rotation in the same direction as the orbital motion. The planets are supposed similarly to have been set in rotation by matter, which had acquired momentum from the star, falling back upon them. The satellites are assumed to have grown from smaller nuclei close to the large planetary nuclei.

The objection was raised by Jeffreys that the collisions between the planetesimals would be so frequent, and would occur with such high velocities, that they would be volatilized into a mixture of gas and fine dust long before accretion could have any appreciable effect. A modified form of the planetesimal theory was consequently proposed by Jeans and Jeffreys. They supposed that the passing star, when near its closest approach, raised a large tidal protuberance on the Sun, from the pointed end of which a stream of matter, in the form of an elongated cigar-shaped filament, was drawn out. Such a filament is longitudinally unstable, and would consequently break up under its own gravitation into a string of separate masses or protoplanets, the smallest at the two ends and the largest in the middle range of distance. Each of these separate masses would move in an elliptical orbit round the Sun. The satellites are supposed to have originated by tidal disruption of the protoplanets by the Sun's attraction at the first perihelion passage after their formation. The small eccentricities of the planetary orbits, and the rotations of the Sun and planets, are explained as in the planetesimal theory.

Plausible as this theory appears at first sight, it is not without serious difficulties. The tidal forces acting on the filament would set it in bodily motion, but could impart little rotation, if any. Jeffreys calculated that, to account for Jupiter's rotation, the amount of matter that would have had to fall back on to it and to be reabsorbed by it would be about 400 times greater than that of all its satellites, which does not seem possible. In the second place, Nölke has queried whether the resisting medium could possibly have brought about the small orbital eccentricities; the majority of the collisions between the particles of the medium and a planet would be inelastic, and consequently a large reduction in the eccentricity could be achieved only by a very great increase in mass through accretion, which is improbable. Further, the material drawn out from the Sun would be at a temperature of a million degrees or more, and under high pressure (exceeding a million atmospheres). Spitzer in 1939 pointed out that it would tend to dissipate rapidly into space; at a temperature of a million degrees hydrogen atoms, for instance, have a mean velocity of about a hundred miles a second. It does not seem possible that condensation could have taken place before the matter had dissipated.

To avoid the difficulty of the rotation of the planets, Jeffreys modified the theory by assuming that, instead of a close approach of the star and the Sun, an actual collision had occurred, somewhat like a 'half-ball' impact. The two bodies would approach each other with enormous speeds and, as they drew near each other, great tides would be raised on them; matter would begin to be ejected from the tidal protuberances before the actual collision occurred. During the collision, the heavy cores of the two bodies would swing round each other in a sharp curve and, separating, move off into space. The nearer portions of the Sun and star would intermingle, and become greatly compressed and heated to a temperature of several million degrees. The shearing motion would cause rapid rotation; as the two bodies separated, a filament of hot gaseous matter, having a rapid whirling motion, would be drawn out between them. The subsequent course of events would be much as in the case of a near approach. Spitzer's objection applies also to this form of the theory.

Jeans had supposed, in order to account for the distribution of angular momentum, that at the time of the formation of the planets the Sun was much more distended than it now is, so that the matter which condensed into the outer planets did not have to be drawn out to a great distance. However, much has since been learnt about stellar evolution, and it is certain that when the solar system was born, a few thousand million years ago, the Sun was almost in its present state. The matter from which Jupiter was formed had, therefore, to be drawn out to a distance about one hundred times greater than the distance of nearest approach between the Sun and the star, while the matter from which Neptune was formed had to be drawn out to about 500 times this distance. The matter would be moving almost radially outwards from the Sun at such distances, and would therefore have but little angular momentum. Russell has shown that, under the most favourable suppositions possible, the angular momentum per ton of the matter drawn out would be less than one-tenth of the average angular momentum per ton of the planetary system.

The conclusion is that no collision theory that supposes the planets to have been formed from matter drawn out from the Sun can be made to work. Russell therefore suggested that the Sun might originally have been a binary star, having a small companion revolving round it at a distance comparable with the distances of the present major planets, and that the intruding star collided not with the Sun itself but with its companion. The angular momentum difficulty could then be avoided, for the angular momentum would be already present in the orbital revolution of the

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companion. This suggestion was investigated by Lyttleton, who succeeded in showing that, under certain conditions, it would be possible for both the Sun's companion and the colliding star to escape from the neighbourhood of the Sun, while at the same time leaving under the Sun's gravitational control sufficient of the matter torn off by the collision to form the planets. Spitzer's objection that the ejected matter would not condense into planets applies in this case also, while the differences between the inner and the outer planets remain unexplained.

To meet the difficulty about condensation, Lyttleton suggested that the planets might have been formed by a two-stage process. If the star was broken up by the collision into fragments, there might have been one or more portions of a sufficient size to be held together by gravitational attraction. As such a fragment cools and contracts, its rate of rotation might increase beyond the limit of stability, when it would break up into two separate bodies; secondary disturbances might have caused smaller fragments to break off, which might have continued with the main bodies to form their satellites. Other fragments might have formed the inner planets and the Moon. At least two separate main bodies would be needed to account for the major planets. A strong objection to this theory is that the rate of rotation required for instability and fission to occur is appreciably faster than the rotation of any of the planets.

Working on the idea that fission may have played an important part in the formation of the system, Lyttleton has put forward another theory. He assumes that the Sun was initially a triple star, having two smaller companions in close proximity. Basing his argument on the view that the evolution of a close binary system is associated with the accretion of interstellar matter by gravitational attraction, the slow increase in the masses of the two components would cause their separation gradually to decrease and eventually bring about their coalescence. The angular momentum of the combined body might be too great for stability; the system would then split up into two bodies which, under suitable circumstances, might both escape from the system, leaving merely a wisp of matter, part of the debris of the cataclysm, from which he supposes that the planets could have been formed. This theory is open to the same objections as the other theories which assume that the planets were formed from matter ejected from a star, and it does not appear capable of accounting for many of the regularities of the solar system.

A catastrophic theory of a different type has been proposed by Hoyle, who supposes that the Sun was once a member of a binary system with a very massive companion, which developed into what is termed a supernova. Such a star passes through a stage of instability in which its brightness increases in a few days by 15 or 20 stellar magnitudes, emitting during its brief eruption as much energy as the Sun emits in the course of a million years. Matter is ejected at a temperature of many millions of degrees, and with speeds up to several thousand kilometres a second, the total amount being perhaps several times the mass of the Sun. Hoyle suggests that an asymmetry of only a few per cent. in this ejection would be sufficient to give the star a recoil that would break its gravitational connection with the Sun, the separation before the outburst being assumed to be comparable with the distance between the Sun and Jupiter.

The material ejected in the initial stages of the eruption would be moving far too fast to be captured by the Sun, but when the eruption was in its final stages the speed of ejection would rapidly diminish, and it is conceivable that a wisp of matter might be captured by the Sun and condense to form planets. There is no difficulty about the angular momentum of the planets, as it is already present in the system, while the direct rotation of the planets is explained as in other catastrophic theories. The objection that matter ejected at an extremely high temperature would be dissipated before it could be captured by the Sun and condense applies with still greater force to this theory. The basic idea underlying it appears to be that the Earth and, according to Hoyle, also the other planets contain relatively small amounts of hydrogen and helium, which are the two elements with the greatest cosmical abundance. Hoyle believes a supernova to be a star with such a high internal temperature that it has used up almost all its hydrogen in the formation of heavier elements. There are, however, strong reasons for believing that the terrestrial planets lost most of their hydrogen and helium in their early history, while the low mean densities of the major planets prove that their very extensive atmospheres still contain a great amount of these light gases.

The failure of the many attempts to form a satisfactory dualistic theory has caused renewed attempts to be made in recent years to develop a monistic theory, not requiring the intervention of any other star or the assumption that the Sun was a component of a double or triple system.

It has been established in recent years that there are in the galactic regions numerous interstellar clouds of gas and of small particles, called smoke for convenience. Whipple supposes that the Sun and planets were formed in such a cloud of gas and smoke, which is assumed to have had a radius of about 30,000 astronomical units and a total mass not much greater than that of the Sun. The cloud contracted under its gravitational attraction, while the Sun was condensing out of the largest aggregation in the cloud. Differential motions have been observed in some of the clouds; Whipple assumes that the planets were formed from condensations in a stream in this cloud. The angular momentum difficulty is thus side-tracked by assuming that the necessary amount was present in the beginning. The condensations, in moving through the cloud, would grow by accretion of matter with zero angular momentum; they would therefore spiral inwards towards the Sun. Whipple gives a qualitative explanation of the planetary rotations, but other regularities in the solar system are not explained, and the theory requires much further development before it can be decided whether it is capable of providing a plausible explanation of the origin of the solar system.

A theory of considerable interest has been developed by Alfvén, which introduces a new consideration. It is based upon the existence of a general magnetic field of the Sun, and on the supposition that electromagnetic forces were predominant in the formation of the planetary system. Assuming the Sun to have a general magnetic field of intensity about 50 gauss, Alfvén remarks that the electromagnetic force on a proton moving along the Earth's orbit would be some 60,000 times greater than the gravitational force arising from the Sun's gravitational attraction.

Alfvén supposes that the Sun in its motion through space entered one of the interstellar gas clouds, consisting of neutral atoms. Under the influence of the Sun's gravitation, the atoms would fall in towards the Sun with accelerated velocities, so that in the vicinity of the Sun the cloud would be heated up. Alfvén assumes that, when the kinetic energy of the atoms becomes equal to the energy of ionization, the atoms would become ionized by collisions. The resulting mixture of positively charged ions and negatively charged electrons would then be subjected to electromagnetic forces from the Sun's magnetic field. Electric currents would be induced in the ionized cloud by the rotating magnetic field of the Sun, and an effect similar to that of the damping of a metal plate rotating between the poles of a magnet would take place. The cloud would be accelerated in the direction of its rotation at the expense of the retardation of the Sun. Angular momentum would, in fact, be transferred from the Sun to the cloud. The angular momentum difficulty can therefore be avoided, if it is supposed that the Sun initially rotated more rapidly than it does at present. With reasonable assumptions, Alfvén calculated that in 100,000 years about 10 per cent. of the Sun's angular momentum would be transferred to the cloud. He finds that the braking effect on the Sun would be greater the higher the heliographic latitude; it is a well-established fact that the Sun rotates less rapidly near its poles than near its equator.

Once an ion has been formed, it will move outwards spirally along the magnetic lines of force and will reach an equilibrium position in the equatorial plane, when it will revolve round the Sun. Assuming that the ions are all ionized at the same distance from the Sun, Alfvén is able to calculate the distribution of mass in the equatorial disk, and finds that it agrees roughly with the actual mass distribution in the range of distance occupied by the major planets. He supposes that the ions and electrons recombine when in their equilibrium position, and that condensation then takes place, planetesimals being formed first and then planets. The outer planets are thus accounted for.

As the distance from the Sun at which ionization would take place is much greater than the distance of Mercury, it is not possible to account for Mercury by this process; the other inner planets, if formed in this way, would have densities less than those of the outer planets. The theory could account for Venus, for example, only if it consisted entirely of hydrogen. A somewhat different mechanism is accordingly proposed to account for the inner planets. It is assumed, quite reasonably, that the cloud contained smoke particles as well as atoms. These particles would fall towards the Sun and would come well within the distance at which the atoms are ionized before being vaporized. When this happens, ionization of the resulting gas occurs and the charged particles are then repelled along the innermost lines of force and finally condense to form the terrestrial planets. Alfvén assumes that the planets would be magnetized, and that the same process would be repeated on a small scale to form satellites.

This theory appears at first sight to be able to account for many points of detail in the structure of the solar system, and to provide rough quantitative estimates of the distribution of mass between the planets, in fairly good agreement with the actual distribution. It is based fundamentally on the existence of a general magnetic field of the Sun. From observations made about thirty years ago at Mount Wilson it was concluded, as mentioned above, that the Sun has a field of intensity 50 gauss, though there remained some doubts about the validity of the result. Recent observers at Hamburg, Mount Wilson, and Cambridge agree that the intensity of the field is now not greater than the probable error of its determination—about 2 gauss. The field may possibly be variable, but the whole basis of Alfvén's theory is rendered doubtful.

There are other objections; ter Haar has shown that ionization by collision will not occur in the gaseous cloud surrounding the Sun, as postulated by Alfvén, and that ionization by solar radiation will not occur at the distances of the outer planets and almost certainly not in the region of the inner planets. It is doubtful, moreover, whether condensation into planets would occur, even if the equatorial disk were formed in the way supposed by Alfvén.

A theory of great promise, which has attracted much interest, has recently been proposed by Weizsäcker. It is a modification of Kant's theory, and assumes that the primitive Sun was surrounded by a rotating shell, consisting of an aggregation of atoms and smoke particles, of total mass about one-tenth the mass of the central Sun, in which each particle moved round the Sun in an independent orbit. The composition of the cloud is supposed to have been the same as that of the Sun, consisting therefore of about 99 per cent. of hydrogen and helium and about 1 per cent. of heavier elements.

Internal frictions within the cloud will change the shape and orientation of the orbits of the various particles until they are eventually reduced to orbits of nearly circular shape in the neighbourhood of the Sun's equatorial plane; the envelope would then be in the form of a disk whose diameter is comparable with the present diameter of the solar system, and whose thickness is less than one-hundredth of the diameter. The disk consists mainly of gas, interspersed with a much smaller quantity of smoke particles, each particle moving practically in an independent gravitational orbit. It would be in temperature equilibrium, there being a balance at any point between the energy received from the Sun and the energy radiated, so that the temperatures would not be greatly different from the present planetary temperatures.

Viscous forces would tend to equalize the angular velocities, slowing down the faster-moving inner parts and speeding up the slower-moving outer parts of the disk. The inner parts, as they slowed down, would fall nearer the Sun, while the outer parts, as they were speeded up, would move further away. This process brings about a gradual transfer of angular momentum from the inner parts of the system to the outer. There would be a gradual dispersion into interstellar space of the hydrogen and helium in the outer portions of the envelope, carrying away the troublesome angular momentum that would have had to be accounted for if the material had fallen into the Sun. It is the mass with low angular momentum that falls into the Sun. Weizsäcker computes that the original density of the envelope would be reduced to the present density of interplanetary space in about 200 million years, which explains why the envelope is not in existence today.

Weizsäcker then considers how quasi-steady states, requiring but little energy for their maintenance, could be formed in the material round the Sun. A group of particles having orbits with the same period of revolution and semi-major axes, but with different eccentricities, will appear, when viewed from axes rotating with the common period, to be describing about the moving origin small ellipses which have a common ratio (2 : 1) of major axis to minor axis, the minor axis pointing to the Sun. They will therefore form a sort of vortex in the rotating system, in which the circulation is in an opposite sense to that of the rotation of the gaseous disk. The vortex can capture other particles only if their angular momentum lies below a certain threshold value, so that there must be an upper limit to its size. If the maximum eccentricity is 1/3, Weizsäcker shows that five such vortices can be fitted into an annulus round the Sun. A stable arrangement is provided by a series of such annuli, each revolving round the Sun, the ratio of the radii of two consecutive annuli then being found to be constant. The radii of the rings consequently follow a law which is a close approximation to Bode's law.

With such a distribution of vortices, there are steep velocity gradients in the neighbourhood of the circles between successive rings of vortices. Large viscous stresses will be set up, and secondary eddies, which may be regarded as in the nature of roller bearings, will form around the rings. The circulation in these eddies will be opposite to that in the vortices and therefore the same as the direction of the disk. It is found that the conditions for condensation would be more favourable in the roller bearings than in the vortices. The process of condensation has been studied in some detail by ter Haar. Condensation can occur only if the vapour pressure of large particles is less than the pressure in the gas, so that more atoms will condense on the particles than will evaporate from them. The nature of the condensation particles is determined mainly by the temperature; it is found that in the outer regions compounds like water, ammonia, and carbon dioxide can condense, but that in the inner regions only the metals and inorganic compounds which are heavier and less abundant can condense. Thus in the first stage of the condensation, the nuclei which form on the inner rings have higher densities than those which form on the outer rings. The second stage consists in growth by accretion of impinging particles sticking to the nuclei, which will occur more rapidly in the outer rings than in the inner. The final stage is growth by gravitational capture, mainly of lighter elements, which is almost limited—as ter Haar shows—to the outer bodies only; this gravitational capture, mainly of the lighter elements, will still further accentuate the difference in the mean densities of the outer and inner condensations.

Weizsäcker calculates that the growth of condensations, practically up to the limit at which no small particles were left, would take about a hundred million years, which is comparable with the dissipation period of the gaseous envelope. The condensations formed in the roller-bearing eddies are the proto-planets. It is not clear, however, why there should be only one planet on each ring. Weizsäcker supposes that the condensations along one ring will come together 'in a manner difficult to visualize'; there would probably be interaction with the material in the wedge-shaped regions between the vortices, and a tendency for adjacent condensations to approach each other. ter Haar finds that the condensation process gives a mass distribution which agrees with the actual distribution in the solar system as well as can be expected from general considerations. The only serious disagreements are that the mass of Mars is much smaller than the theory requires for a planet at the distance of Mars from the Sun, and the theory requires a planet between Mars and Jupiter; the asteroids, however, may be fragments of such a planet which has disrupted. The slowness of rotation of the inner planets can be adequately ascribed to tidal friction, caused by tides raised on them by the Sun.

The formation of the so-called 'regular' satellites can be attributed to an analogous process of condensation inside the planetary atmospheres; the relative distances of the satellites follow laws of the Bode type. The 'irregular' satellites, viz. the Moon, the two satellites of Mars, and the outer satellites of the major planets, are assumed to be condensation products that were captured by the planets at a later stage. Gravitational capture would not have played any significant role in the building up of the regular satellites because of their small mass, which accounts for the observational fact that their densities are higher than the densities of their primaries, but lower than the densities of the inner planets.

Weizsäcker's theory therefore offers a plausible explanation of the principal features of the solar system: the common direction of revolution and rotation of the planets and satellites; the essentially common plane of their revolution; the small inclinations of their equators to this plane; the slower rotations and higher mean densities of the inner planets relative to the outer planets; and, by and large, the mass distribution and Bode's law. It also provides a workable scheme for the loss of excess angular momentum, though the present very slow rotation of the Sun is not fully accounted for. No other theory yet proposed has been so successful. The theory is, moreover, fairly amenable to mathematical treatment, and many details can be investigated quantitatively. The catastrophic theories are not suitable for rigid mathematical treatment and at best can give only qualitative results.

In the investigation of the origin of the solar system, we labour under the disadvantage that we do not know whether planetary systems are exceptional. If the solar system had a catastrophic origin, planetary systems must be of extreme rarity; if, on the other hand, it was formed in the way Weizsäcker supposes, they should be of frequent occurrence, particularly in the Milky Way, where the interstellar clouds are abundant. The main limitation is that the temperature of the central star must not be too high, for otherwise condensation would not be possible; none of the very hot stars could be expected to have planetary systems. It is not beyond the bounds of possibility that observational evidence may eventually provide some information about the frequency of planetary systems. We should then have at least an indication whether or not such systems are of catastrophic origin.

The Muslim tradition in astronomy

H. J. J. WINTER

Muslim contributions to astronomy influenced the development of the science for roughly a thousand years. They were in two main fields. On the one hand, we are indebted to the Muslim astronomers for the astrolabe, an instrument which in its latest—and often exquisitely wrought—forms permitted many determinations to be made, for example, of the longitude of a planet in the ecliptic. On the other hand, they were responsible, through their great willingness to co-operate with scholars of other nations, for the wide diffusion of astronomical knowledge.

The Giralda Tower in Seville, completed *c.* 1195, was the first astronomical observatory in Europe. Yet it represented a Muslim tradition in observational technique which had its origins some four hundred years before, in the labours of those scholars working under the patronage of the early ‘Abbāsid caliphs such as Al-Manṣūr and Hārūn al-Rashīd. Among them were Ibrāhīm al-Fazārī, who first constructed astrolabes, his son Muḥammad, and two men who were responsible for the surveying of the site of Baghdad before its foundation in 762—namely Māshā’allāh (Messahalla), and Al-Manṣūr’s own astrologer Al-Naubakht.

This glorious tradition, old as it then was, did not end in Seville: through Spain it influenced Europe, and in its eastern expansion it had a profound effect on Asian astronomy until the early eighteenth century. We can trace it in the Mongol observatories at Marāgha and Khānbaliq, in the observatory at Samarkand set up by order of the Turkish prince Mīrzā Ulugh Beg around 1420, and finally in the observatories at Delhi, Benares, Jaipur, and Ujjain, established by the Hindu Mahārāja Sawāī Jai Singh (1686–1743) at a time when the use of the telescope in Europe was rendering obsolete those instruments, often of exquisite workmanship, in which the Muslims took so much pride.

The principal instrument of medieval astronomy was the plane astrolabe. It is admirably and fully described by Willy Hartner in Vol. III of the great *Survey of Persian Art* edited by Arthur Upham Pope. The plane astrolabe or *astrolabium planisphaerium* (Arabic: *asṭurlāb saṭḥī*) consisted of a circular disk or *mater* (Arabic: *’umm*) with a raised rim and an axis or pin at its centre upon which rotated certain additional parts. These parts defined the functions of the front and the reverse of the astrolabe, which were essentially different though complementary. Thus, on the reverse of the instrument there rotated, over an angular scale, the *alidade* or sighter, which, when the instrument was suspended vertically, enabled the observer to read off the angular elevations or altitudes of heavenly bodies. The function of the reverse of the instrument was thus observational, and from it derived the mariner’s astrolabe used by Columbus, and, later on, Hadley’s quadrant. On the other hand, the front of the instrument was theoretical in function; it was in fact an elaborate calculating machine. The graduated rim of the disk or *mater*, the inner surface of which often had recorded on it the latitudes and longitudes of important astronomical centres, and the various additional disks (*ṣafā’iḥ*), supplying specialized information, which could be fitted over the central pin and allowed to rotate within the *mater*, facilitated a multitude of computations. These several additional disks, usually of thin brass, had inscribed on them almucantars,[1] azimuth circles, hour circles, etc., for various latitudes. One particular disk, of open-work design, called the spider or *rete* (Arabic: ‘*ankabūt*) indicated the ecliptic, the signs of the zodiac, and, by means of pointed ‘branches’ or *shazāya*, the positions of certain fixed stars such as Vega and Arcturus.

This ‘*ankabūt* leads us immediately to the principle of the front of the astrolabe, which now demands a few lines of explanation. The principle is that of stereographic projection, which, according to Neugebauer, may have been known as early as the time of Hipparchus (150 B.C.). Imagine a sphere, with a diametral plane through which the north-south line passes perpendicularly, and let there be drawn upon the surface of the northern hemisphere various circles; then if the points upon the circumference of one of these circles are joined directly to the south pole of the sphere, an imaginary cone will be formed whose section at the diametral plane will be a circle on that plane. This last circle and others similarly obtained are stereographic projections on the diametral plane. If

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[1] From an Arabic term denoting parallels of altitude or circles parallel to the horizon.

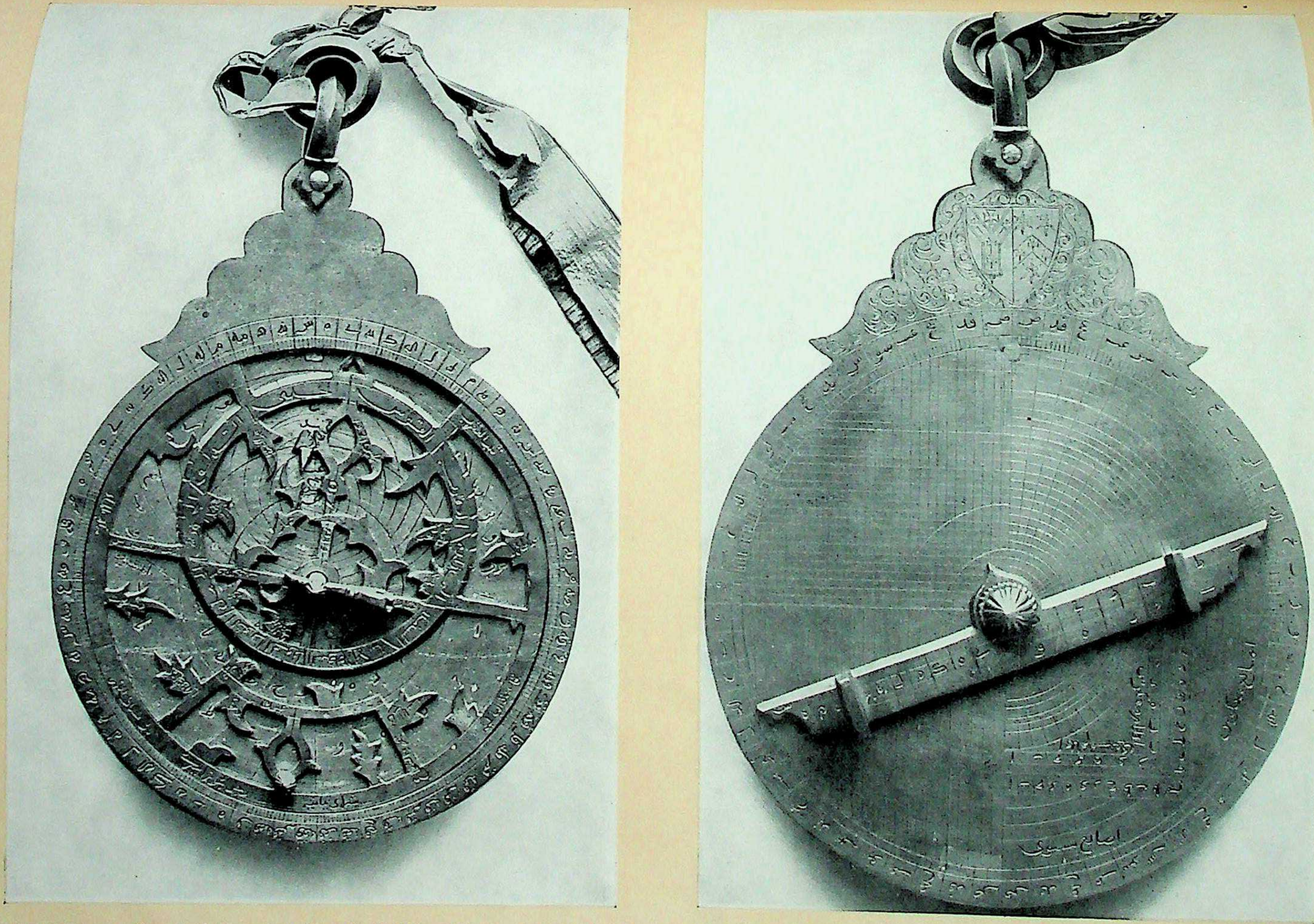

FIGURE 1 – *An astrolabe presented to the Bodleian Library, Oxford, by William Laud, Archbishop of Canterbury. It probably dates from the early seventeenth century.*

(× ½)

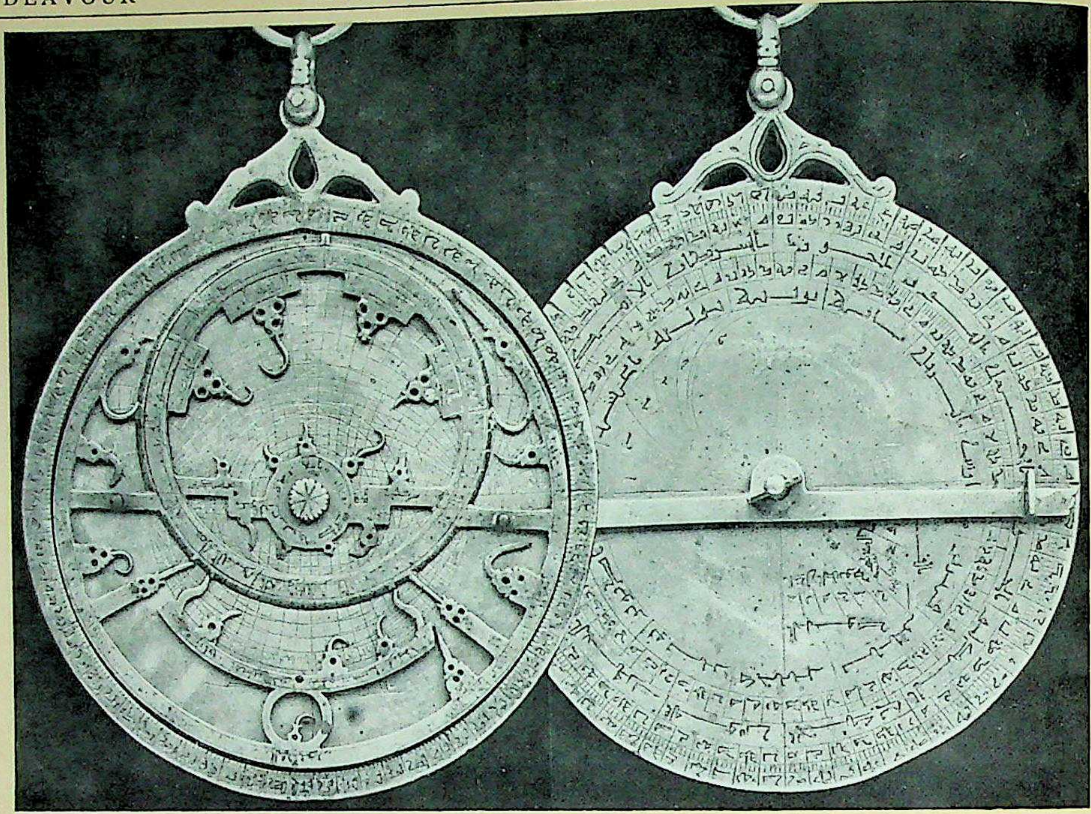

FIGURE 2 – *A finely wrought Moorish astrolabe of the thirteenth century.* (× ½)

(*Figures 1 and 2 reproduced from Gunther's* Astrolabes of the World.)

now we replace this sphere by the celestial sphere, and, on the assumption of a geocentric theory and circular planetary orbits, make stereographic projections upon the equator, the concentric circles so derived may be represented on a much reduced scale on the front surface of the astrolabe. In practice, the rim of the *mater*, for one single latitude, represented the projection of the Sun's orbit at winter solstice, and the other circles, such as the projection of the summer solstitial circle, fell within it. In this simplest case of a given latitude, the *mater* became a *ṣafīḥa* (singular of *ṣafā'iḥ*) bearing the appropriate stereographic projection of the heavens. The rim, divided in degrees, measured equinoctial time (right ascension). The '*ankabūt* represented the ecliptic, which is a circle touching the solstitial circles, and as it rotated about the central pin of the astrolabe, it represented the path of the fixed stars around the north pole of the heavens, such that a pointer on its rim which made contact with the scale on the rim of the *mater* gave, at the point of contact, the rotation of the ecliptic in right ascension. The 'off-centre' disposition of the '*ankabūt* is clearly seen in the figures. As an instance of the several uses to which the astrolabe was put, we may mention the determination of the approximate longitude of a planet in the ecliptic; using the *alidade* on the reverse of the astrolabe, the altitudes of the planet and of a fixed star were found experimentally, and this information then 'transferred' to the front of the instrument, the '*ankabūt* being set on the appropriate almucantar of the fixed star. The longitude of the planet was read from the degree of the ecliptic lying on the almucantar corresponding to the measured altitude of the planet.

Among other instruments known to the Muslims were the spherical astrolabe (*astrolabio redondo*), which comprised a celestial globe surrounded by a spider, and facilitated calculations in spherical trigonometry; the linear astrolabe, on which the dome of the heavens was projected in a straight line; various armillae, adaptations of the armillary sphere of the ancients, in which the poles of the heavens were represented, together with rings for the ecliptic and zodiac, and two colures or great circles dividing equinoctial and ecliptic into four equal parts at the equinoctial and solstitial points of the ecliptic; instruments with sighting equipment consisting essentially of arcs of a circle, such as the quadrant and sextant, for finding the altitudes of celestial bodies; and improved versions of the sun-dial for measuring time. The great reputation of 'Alī ibn 'Īsā al-Asṭūrlābī (*c.* 830) of Baghdad and Damascus, and Al-Zarquālī (*c.* 1080) of Córdova, in the making of astrolabes was well deserved. Fine astrolabes were still being produced in India in the days of the Moghul emperors.

A study of the shadows cast by the simple sundial or gnomon (*a*) when standing vertically upon a horizontal surface, and (*b*) when projecting horizontally from a vertical wall, laid the foundations, through such scholars as Al-Battānī (Albategnius, *d.* 929), and Abū-l Wafā' (*d.* 998), of modern trigonometry, and with Al-Ḥasan al-Marrākushī (*d.* 1262), became, in Morocco, an elaborate system of gnomonics.

The direction of development in Muslim instrument design is especially interesting. Whereas in the West accuracy was achieved by such measuring devices as the vernier and micrometer, the emphasis in the East was upon size and rigidity; Al-Khujandī (*c.* 1000) used a sextant of radius 57 ft. 9 in. and, according to John Greaves (*infra*), the great quadrant at Samarkand was of about the same height as St. Sophia in Constantinople, i.e. 180 ft, while Jai Singh, following the Muslim tradition, erected huge masonry instruments in India.

In the first half of the ninth century the *Almagest* of Ptolemy was translated into Arabic by the Jewish astronomer and physician Sahl (Rabbān) al-Ṭabarī, and the earlier Muslim observations made under the 'Abbāsid caliphate were mainly concerned with the verification of the information so derived, e.g. the value of the obliquity of the ecliptic. Ḥabash al-Ḥāsib, working at Baghdad in the reign of Al-Ma'mūn, measured time by the altitude of the Sun, and completed some astronomical tables.

The greatest of the Baghdad astronomers was Al-Battānī, who tested many of Ptolemy's results. He obtained improved values of the precession of the equinoxes and of the obliquity of the ecliptic and showed that the Sun's apogee had changed its position since the time of Ptolemy. He also constructed more accurate tables of the Sun and the Moon than were then in use.

Following upon the many astronomers of the 'Abbāsid period were those who worked under the patronage of the Buwayhid sulṭāns, the 'Umayyad caliphs of Córdova, and the Fāṭimids of Egypt. Ibn al-A'lam compiled accurate astronomical tables in the time of the Buwayhid 'Aḍud al-Dawla, and Ibn Yūnus completed in 1007, at the Cairo observatory, the Hakemite Tables. These researches were soon followed by the Toledan Tables edited by Al-Zarqālī, the reformed calendar of 'Umar Khayyām at Nīshāpūr, whose arrangement of 8 leap years in each period of 33 years is more accurate than that adopted in the Gregorian reform of the calendar in 1582, and the Sinjaric Tables of Al-Khāzinī of Merv. Such events leave no doubt as to the widespread influence of Muslim astronomy.

On the sacking of Baghdad in 1258 by the Īl-Khān Hūlāgū, grandson of the Mongol conqueror Ghengis Khan, Muslim astronomy became centred upon Marāgha in Adharbaijān, where a great observatory was established under the direction of Naṣīr al-Dīn al-Ṭūsī. This observatory, which is mentioned by Rashīd al-Dīn[1] in his *Universal History*, was of great importance as a cultural focus, in spite of its very short life.[2] It drew competent astronomers from various and distant parts of Asia and was equipped with specially fine instruments, not surpassed for more than three centuries by any instruments in Europe. Among Al-Ṭūsī's assistants were Al-'Urḍī of Damascus, Fakhr al-Dīn from Mūṣul, Al-Khalāṭī from Tiflīs, Najm al-Dīn Dabīrān from Kazvīn, and Ibn al-Fūṭī (Al-Shaibānī) from Baghdad. Others who spent some time there were Abū-l Faraj (Barhebraeus), who was primate of the Eastern Jacobites, and Muḥyī al-Dīn al-Maghribī, an astronomer from western Islām, while Chinese scholars, such as Fu Meng-chi, were said to have been sent there to study on the orders of Hūlāgū. The more important Greek writings on astronomy and geometry were translated at the Marāgha observatory, and some of them have survived only in the Arabic version. These translations had a great influence on the development of Arabic astronomy.

Sino-Persian collaboration in astronomical studies is a special feature of the Yüan (Mongol) Dynasty during the latter part of the thirteenth century, when the Central Asian caravan routes were under the Mongol control. Although Hūlāgū had died in 1265, the astronomical tables—Zīj-i-Īlkhānī—begun by Al-Ṭūsī at the Great Khān's request soon after the fall of Baghdad, saw completion around 1272, and the early stages of this compilation no doubt inspired Kublai Khān, who had been on friendly terms with his brother Hūlāgū and perhaps wished to emulate him, to set up a further observatory at the new capital city of Khānbaliq in China. We have names such as 'Isā the Mongol (Ai-Hsieh), Jamāl al-Dīn (Cha-ma-li-ting), and Kuo Shou-Ching to remind us of this spirit of co-operation. Jamāl al-Dīn left Marāgha soon after the death of Hūlāgū and reached Khānbaliq in 1267, carrying with him, according to the book Yüan Shih, drawings, or perhaps models, of seven Muslim instruments, and Willy Hartner thinks that an extant armillary sphere dated 1279 was made by Kuo Shou-Ching in accordance with a design supplied by Jamāl al-Dīn. Kuo Shou-Ching also probably introduced Muslim spherical trigonometry, on which subject Al-Ṭūsī had written a monumental treatise, *Kitāb shakl al-qaṭṭā'*, to Chinese mathematicians. The Muslim tradition, however, seems never to have made a strong impression in China, the two surviving Mongol instruments having their own particular circular measure of 365¼ divisions, with 100 subdivisions, each divided again by 100. In fact, China received again, from the Jesuits in the seventeenth century, precisely the same information which it had tended to neglect in the thirteenth—information which had proceeded westwards from the same Muslim origins and had reached European scholars through the monumental *Libros del saber de astronomía* (*c.* 1276), of Alfonso X of León and Castile, and the Alphonsine Tables compiled under his direction (*c.* 1272) by the Hispano-Jewish scholars Judah ben Moses and Isaac ibn Sid.

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[1] Physician to Hūlāgū's successor Abaqā Khān.

[2] It is said to have been in ruins by 1340.

Yet it was not in Spain alone that the Muslim astronomy flourished. There was a school at Samarkand in the time of Tīmūr-Lang which burst forth into remarkable activity under the enlightened patronage of his grandson Mīrzā Ulugh Beg (*b.* 1394), who built an observatory there. From 1420, until this prince's assassination by his son in 1449, fine masonry instruments of great size were erected, and the observations made with them were used in the compilation of the Samarkand Tables entitled Zīj Ulugh Beg which appeared in 1437. Ulugh Beg's star catalogue was of high accuracy for its time, and is noteworthy as the first essentially new catalogue since Hipparchus. Both the Īlkhānian and Samarkand Tables had tremendous influence; portions were rendered into Latin by John Greaves, Savilian Professor of Astronomy at Oxford in the time of Charles I, and had their due effect upon Western astronomy. Turkish influences were strong at Samarkand. Ulugh Beg and the second director of his observatory, Qādī Zāde al-Rūmī, were Turks, while the astronomer Al-Qūshchī worked both at Samarkand and at Constantinople. Excavations around the great quadrant at Samarkand in 1909 brought to light metal rails and a graduated marble scale.

Jai Singh II of Jaipur, and his son Madhu Singh, bring to an end this long and illustrious tradition, stretching over almost a millenium of Islamic history. Though a Hindu, as was his chief assistant Jagannāth, Jai Singh may be regarded as the successor to the astronomers of the Moghul period in that, in spite of a knowledge of both European and Hindu astronomy, he followed closely the Muslim methods, set about improving the Muslim astronomical tables, and copied the instruments of Ulugh Beg. Jagannāth was employed because he knew Arabic, and he produced a Sanskrit translation from the Arabic version of Ptolemy's *Almagest*. Not unmindful of European researches (he sent Father Figueredo to Portugal *c.* 1728 and was visited by Father Boudier in 1734, while he was acquainted with the work of Flamsteed (1646–1720), La Hire (1640–1718), and their predecessors), Jai Singh nevertheless followed mainly, in the erection of his observatories at Delhi (1724) and other centres, and in the compilation of his new tables, the Muslim line of investigation exemplified by the technique of such astronomers as Al-Ṭūsī and Ulugh Beg.

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Some smaller whales

H. BOSCHMA

As many of the existing figures of whales and dolphins are inaccurate, it has been the policy of the Leiden Museum of Natural History to obtain coloured illustrations of a number of stranded animals of the group, based on accurate measurements. Whenever there became available—in a good state of preservation—a cetacean that was of scientific interest, an accurate oil painting was made by the late Mr M. A. Koekkoek. Some of these are reproduced in the present article, showing the left side, the lower surface, the head in dorsal view (and in one case one of the flippers), of a Pygmy Sperm Whale, a New Zealand Scamperdown Whale, and two Bottle-nosed Whales, stranded between 1925 and 1931 on the Dutch coast.

The Pygmy Sperm Whale (*Kogia breviceps*) in general appearance is dolphin-like, but the mouth terminates behind the tip of the snout. The teeth are normally confined to the lower jaw. In the Pacific and Indian Oceans the species is not uncommon around Australia and New Zealand, and it is known from the waters of South Africa, India, Ceylon, Indo-China, and the East Indies. It has been reported near Japan, and there are two records for the Eastern Pacific (Mexico and Peru). In the North Atlantic, twenty strandings on the American coast, from Florida to Nova Scotia, are listed by Allen [1], while on four occasions the species came ashore in European waters. Delage [2] reported upon the first of these, a male, stranded near Roscoff in Brittany in 1905. The head was brought to the *Bureau de la Marine*; the body was left for the dogs to eat their fill. What remained, together with the head, formed the subject for elaborate studies by Le Danois [3, 4]. In the last of these publications the author remarks that in 1910 a Pygmy Sperm Whale came ashore on the Ile d'Oléron; of this animal the museum at La Rochelle was unable to obtain more than the skin, which was afterwards stuffed. The third European specimen, the one figured here, was found on the beach at Noordwijk aan Zee in Holland in 1925. Van Oort [5] remarks that the carcass was in a comparatively fresh state, only slightly mutilated by destructive hands. It was a female of a length of 2·95 m. The colour may be described as follows. Back, steel blue, with a partial tendency to slate grey, gradually becoming lighter on the sides. Under surface, ivory white from the tip of the lower jaw to slightly behind the vent. Upper surface of the flippers, dark blue; under surface whitish. Under parts of the tail and flukes, a lighter blue than the remainder of the tail. In the white of the lower surface there were a number of brownish spots which may have been caused by the beginning of decomposition in the skin. The specimen dealt with here is the only one in which a decidedly bluish tinge of the darker parts was to be observed. As a rule the darker parts of stranded Pygmy Sperm Whales are described as black or jet-black, exceptionally as slatey grey. In the literature on the subject the colour of the belly has been described as white, dirty white with a tinge of yellow, or pinkish.

According to information kindly supplied by Dr F. C. Fraser, a fourth specimen, stranded on the Portuguese coast, is preserved in a stuffed condition in the marine institute at Dafundo near Lisbon.

The shape of the dorsal fin of the Pygmy Sperm Whale is subject to considerable variation, as already stated by Allen [1] and by Hale [6]. In the figure in Norman and Fraser [7], this fin is inconspicuous; in the specimen figured in Fraser and Parker (by Simon) [8] it is long and pointed. The animal represented in figure 1 had a low, blunt fin.

In all the Pygmy Sperm Whales of which the blowhole has been described this organ is stated to be in an oblique position. In the specimen dealt with here this point of asymmetry was not apparent.

The New Zealand Scamperdown Whale (*Mesoplodon grayi*) was observed for the first time in the Chatham Islands, where a school of about twenty-eight was stranded in 1874. Three heads were sent to Julius von Haast, the director of the then recently founded Canterbury Museum at Christchurch. He described the animal as a new species [9], the outstanding specific character of which was a row of minute teeth partially protruding from the gum on each side of the upper jaw, and varying in number from seventeen to nineteen. Each row began just behind where, in the lower jaw, a fairly large tooth is situated in each ramus. Shortly afterwards, von Haast [10] received four specimens from the New Zealand coast, each again with distinct rows of minute teeth. Later on, many specimens came into the collections of various museums, and it has been observed, whenever a specimen of the New Zealand Scamperdown Whale (a name that came into use soon after the description of the species) could be studied in the flesh, that the upper jaw proved to possess a row of minute teeth on each side.

Up to 1950, *Mesoplodon grayi* was known to occur in the seas around New Zealand, New South Wales, Victoria, South Australia, South Africa, and Patagonia.

FitzSimons [11] lists Sowerby's Whale (*Mesoplodon bidens*) among the mammals of South Africa, considering the animal stranded near Port Elizabeth in 1910 as the first recorded specimen of that species from the Southern Seas. In the volume cited, there is a photograph of the stranded specimen and one of its skull in side view. In 1910 these same photographs were sent by FitzSimons to London, where Lydekker [12] correctly identified the specimen as *Mesoplodon grayi*, pointing to the fact that the teeth in the lower jaw are distinct from those of *Mesoplodon bidens*.

Sowerby's Whale and the New Zealand Scamperdown Whale have one character in common that may easily lead to misidentification: the teeth in the lower jaw occupy exactly the same place, and as far as they protrude over the margin of the jaw they may have a similar appearance. In the Leiden Museum there is a skeleton of a female Beaked Whale of 4·60 m, stranded near Loosduinen on the Dutch coast in 1927; on account of the position and the shape of the teeth in the lower jaw it was provisionally identified as Sowerby's Whale (*Mesoplodon bidens*), but it eventually proved to be a specimen of the New Zealand Scamperdown Whale (*Mesoplodon grayi*). The skull has the typical characters of the latter species, and, moreover, on each side of the upper jaw there is a row of twenty-two small teeth—for the greater part embedded in the gum, but with their tips freely protruding (Boschma [13]). Fortunately the whale arrived on the beach in mid-winter in a completely undamaged state, so that an accurate coloured picture could be made. The latter is reproduced as figure 2, and is the only picture in existence of the complete animal. The colour of the specimen is black to dark slate grey on the back, gradually merging into a brownish grey on the sides. The ventral surface is of a light grey with a brownish tinge, with the exception of a broad darker median area, which becomes mottled anteriorly and vanishes in the region of the flippers. The flippers and the tail-flukes on both sides are very dark grey to black, the edges of the flippers having a lighter border. The lower jaw and the throat are of a very light grey, almost white in some places. On the edges of the upper jaw, and around the navel, the genital aperture, and the vent there are whitish lines. On the sides there are a single white streak and several smaller white patches which ought possibly to be regarded as scars. In New Zealand specimens, according to von Haast [10], the colour of the back is black, getting a little lighter near the tail, where it assumes a dark slate tint; the lower surface is reddish brown, assuming a blacker hue on both sides near the tail. The animal stranded near Port Elizabeth was jet-black all over (Lydekker [12]); Cabrera and Yepes [14] also describe the colour as black.

It must be admitted that our knowledge of the distribution of the Beaked Whales, especially as far as concerns the species of the genus *Mesoplodon*, is very scanty. The commonest species, Sowerby's Whale (*Mesoplodon bidens*), is restricted to the North Atlantic; it has been recorded from the European coasts as well as from the North American. True's Beaked Whale (*Mesoplodon mirus*), originally found on the Atlantic coast of North America, has been reported three times in British waters since 1917 (Harmer [15]). Another rare species, *Mesoplodon europaeus*, was described from a specimen found floating at the entrance to the English Channel; later it became known from the North American Atlantic coast. *Mesoplodon bowdoini* was known until recently only from two skeletons found on the coast of New Zealand (Fraser [7]); Hubbs [16] gave an account of a specimen stranded in Southern California. There is one species of the genus (*Mesoplodon densirostris*) that appears to have a random distribution, as the seven known specimens are from such widely separated localities as the Seychelles, Lord Howe Island, South Africa, Massachusetts, New Jersey, and Madeira. The few other species of the genus seem to have a rather restricted distribution.

In the Bottle-nosed Whale (*Hyperoodon rostratus*) the snout is more sharply defined from the remainder of the head than in any of the other Beaked Whales, and consequently the head has a prominent 'forehead' that, especially in old males, is strongly bulging. The maximum size is about 9 m for males and slightly over 7 m for females.

The colour of the Bottle-nosed Whales stranded

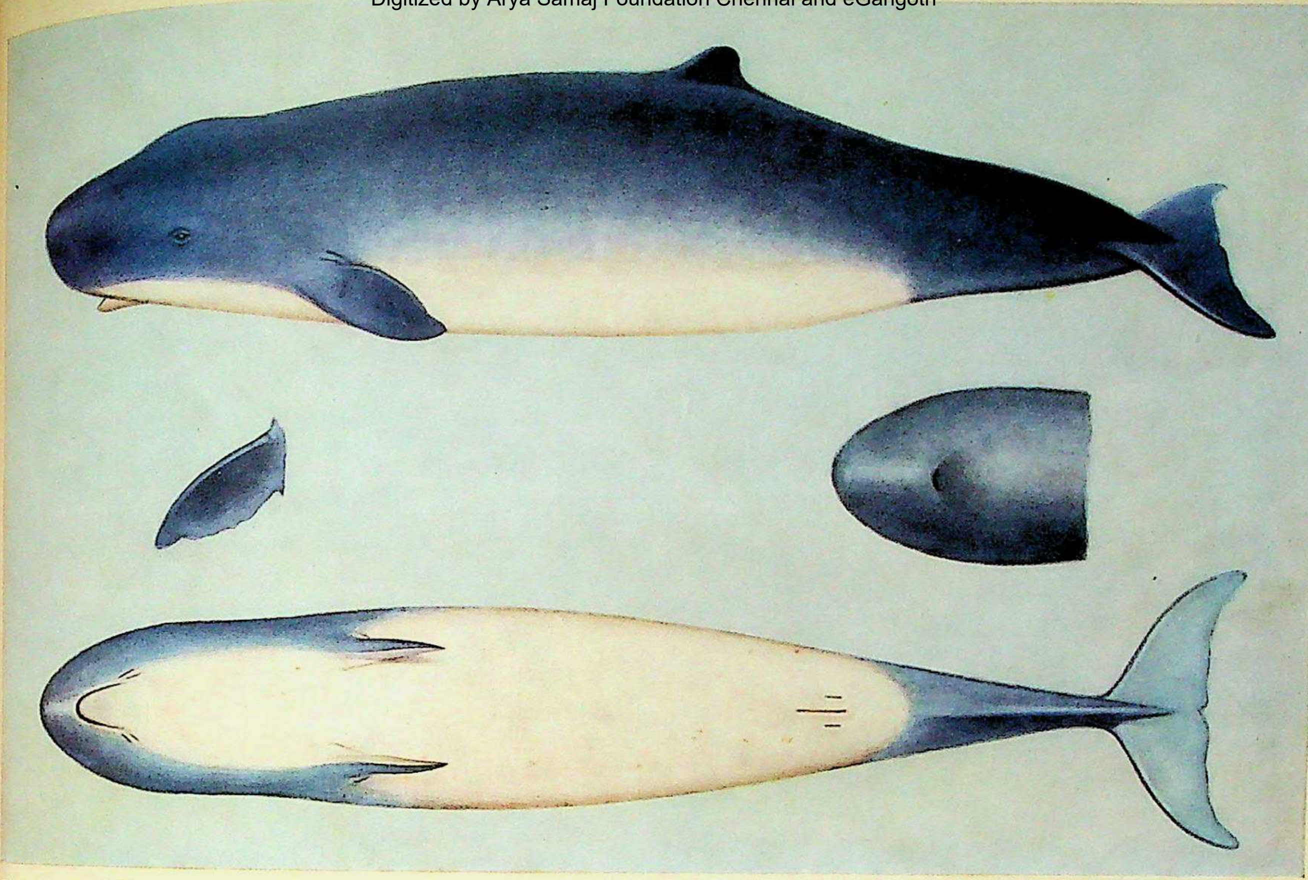

FIGURE 1 – *Pygmy Sperm Whale* (Kogia breviceps), *adult female, total length 2·95 m. Noordwijk aan Zee,* 1925. *Showing left side, lower surface of body, dorsal view of head, and one flipper.*

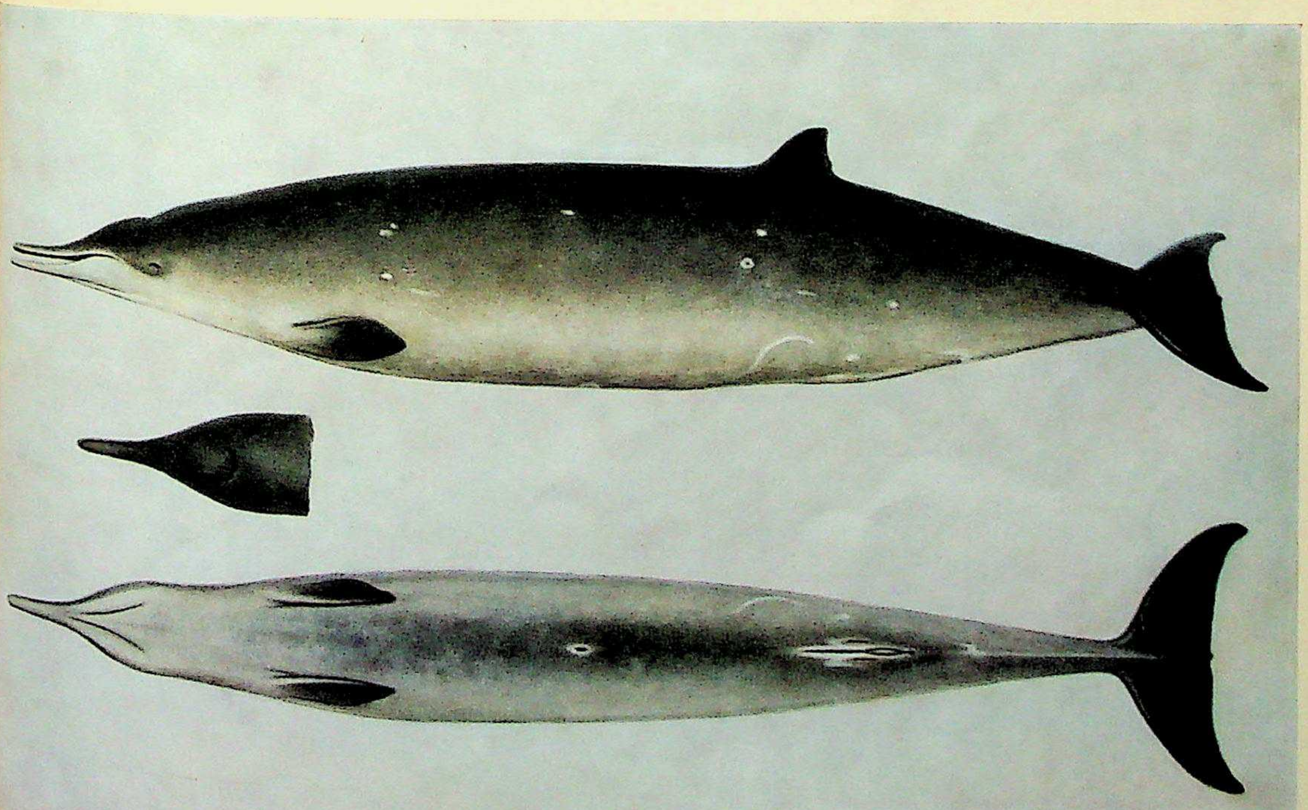

FIGURE 2 – *New Zealand Scamperdown Whale* (Mesoplodon grayi), *female, total length 4·60 m. Loosduinen,* 1927. *Showing left side, lower surface of body, and dorsal view of head.*

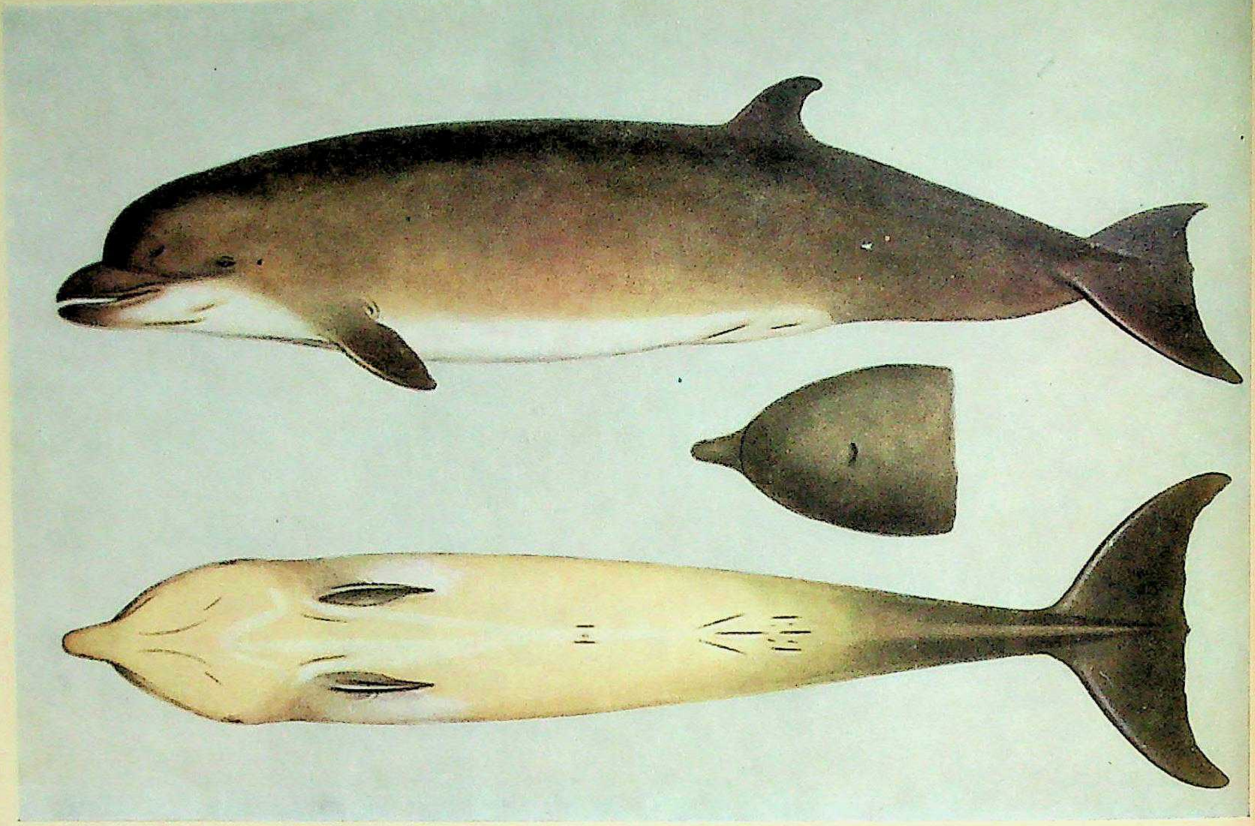

FIGURE 3 – *Bottle-nosed Whale* (Hyperoodon rostratus), *young male, total length* 4·20*m. Off Texel,* 1927. *Showing left side, lower surface of body, and dorsal view of head.*

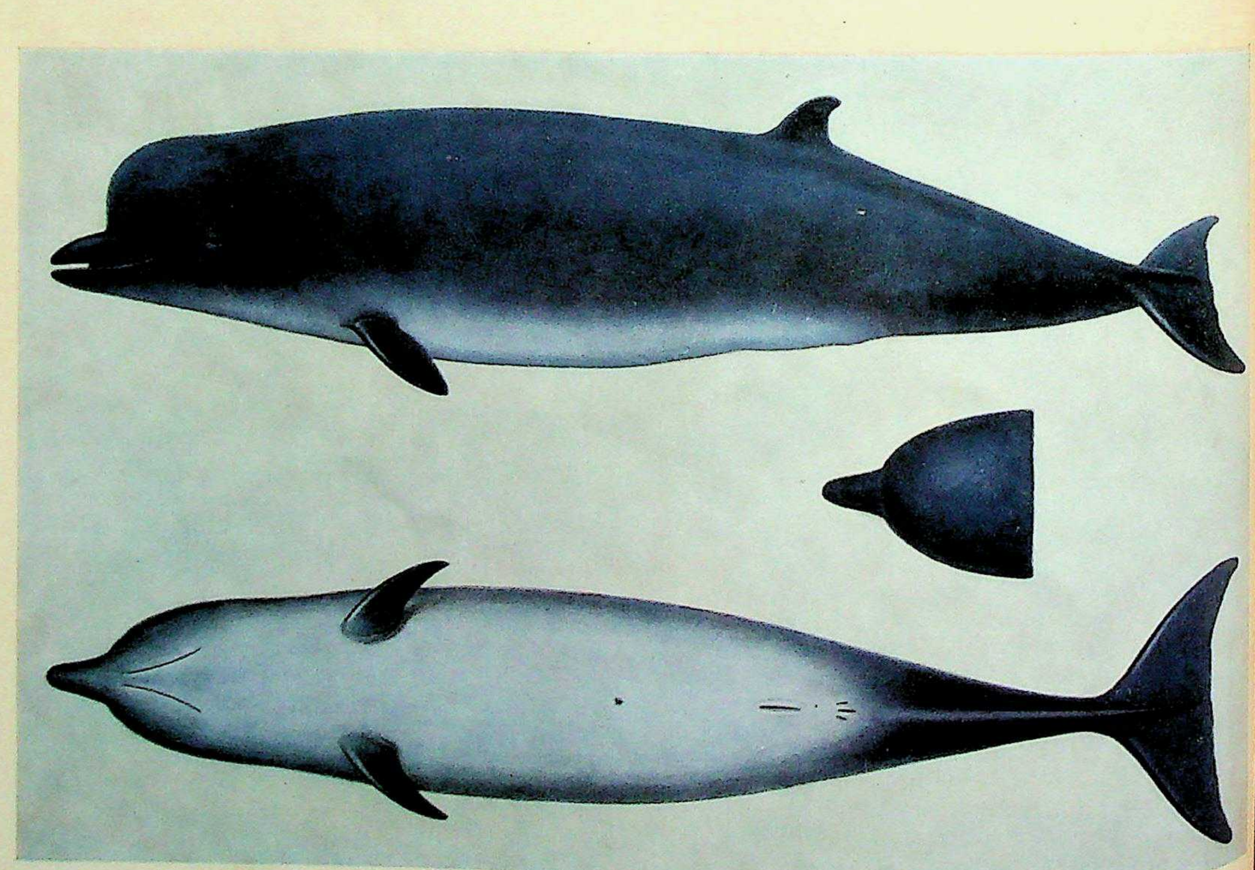

FIGURE 4 – *Bottle-nosed Whale* (Hyperoodon rostratus) *male, total length* [illegible] *Near Waarde,* 1931. *Showing left side, lower surface of body, and dorsal view of head.*

on various European coasts up to the later part of the nineteenth century was almost invariably described as blackish grey. The under parts were generally stated to be of a somewhat paler colour. At present, it is an accepted view that the colour changes with age. David Gray [17], commander of the whaling steamer *Eclipse*, who captured numerous Bottle-nosed Whales, gives the following account: 'They vary in colour from black in the young to light brown in the older animals. The very old turn almost yellow, the beak and front of the head being quite white, with a white band round their necks; all of them are greyish-white in the belly.' Substantially, this statement is corroborated by Axel Ohlin (see Millais [18]). In later years, however, specimens were obtained that formed exceptions to the statement quoted above. Harmer [19], when considering a young specimen with a good deal of white, and a much larger one of an almost entirely black colour, came to the conclusion that 'the alteration in colour is not always so regularly progressive as it has been described to be by previous observers.' In this connection two young Bottle-nosed Whales from the Dutch coast are of interest. One of these, a young male of 4·05 m, stranded near Egmond, was described by Junge [20] as having along the sides a distinct sepia-brown area between the black of the back and the yellowish white of the belly. Moreover, Junge refers to the young male specimen (figure 3), captured off Texel in 1927, length 4·20 m. In this animal the entire back was dark greyish to chestnut brown; the flippers and the tail had the same colour. Towards the lower surface the sides gradually turned into a lighter brown, which passed to yellowish white on the under parts. Here the light colour extended from the under side of the head to the region of the vent; it continued as a narrow median light-brown stripe on the tail. On the other hand, a much larger young male, stranded near Waarde in 1931, length 5·29 m (figure 4), shows in every detail the colouring that is regarded as characteristic of young animals. The back and the greater part of the sides are dark slate grey to black, and the same colour is found on the flippers and on the flukes. The under surface, from the throat to the region of the vent, is grey.

These two Bottle-nosed Whales (figures 3 and 4) show some further interesting points. Though both are comparatively young, they already show distinct differences in the shape of the head. In the brownish younger specimen the 'forehead' is far less bulging than in the blackish older specimen. The peculiar development of the head in the male Bottle-nosed Whale therefore starts at a comparatively early age. Moreover, the two specimens in ventral view show distinctly the two converging throat grooves that are characteristic of all Beaked Whales. It has been observed that in embryos four of these throat grooves may occur. It is interesting that the brownish younger specimen shows, next to the pair of conspicuous throat grooves, a pair of shorter grooves of the same kind, undoubtedly the rudiments of originally more fully developed grooves.

Many more observations are needed before the variation in colour in cetaceans (and, as a matter of fact, the variation in many other characters) can be sufficiently known.

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The form of coral reefs

C. M. YONGE

The structure of coral reefs is the result of the combined action of several powerful forces—especially the growth of the living organisms and the action of wind-driven seas on exposed surfaces. Consideration of the relative contributions of these forces explains the curious ring-shaped structure of the oceanic atolls; it further suggests strongly that this is indeed the only possible form in which coral islands could be built up and maintained in mid-ocean.

Living coral reefs are associations of marine animals and plants found only within shallow tropical seas where temperatures seldom fall much below 20° C. They are thus largely confined to the tropics, although extending beyond these limits where there are outflowing warm currents, as in the Atlantic around Bermuda. The most conspicuous organisms on most reefs are the stony corals, or Madreporaria, animals essentially similar to sea anemones, but with a calcareous skeleton, from the surface of which they expand, and with protective cups or calices into which they are able to withdraw. Massive, branching, foliaceous, or encrusting colonies are formed according to the species, modified sometimes by environmental conditions. These are reef-building corals, to be distinguished from related species that inhabit cold or deep seas. With them live representatives of all the great groups of marine animals. There are allied soft corals (Alcyonacea) and horny corals (Gorgonacea), the latter especially numerous on West Indian reefs, also numerous molluscs, worms, and crustaceans, with echinoderms, such as star fishes, sea-urchins, and many types of sea cucumber or *bêche-de-mer*. Smaller animals abound in crevices and under stones. Plants are no less important. Seaweeds like those on temperate shores occur—usually with limited life, one species succeeding another throughout the year—but both green and red calcareous algae form permanent growths of prime importance in the maintenance of reefs.

A reef is geologically a mass of limestone formed from the skeletons of corals, mingled with shells ranging from those of giant clams to the spirally chambered shells of minute foraminiferous protozoa. Only the surface of this mass with its fissures is inhabited. Coral skeletons and large shells may be regarded as bricks, and smaller shells with broken fragments as rubble. Unaided, these could form no secure reef. Essential cement is provided by plants, the pink calcareous nullipores, largely *Lithothamnion*, which form an encrusting ridge, as shown in figures 1 and 10, where the surf is great. The green calcareous weed, *Halimeda*, is often abundant in shallow water, forming branching growths. Its whitened fragments are common in coral sands.

The great mass of a reef is nourished from the surrounding sea. From this the corals obtain the microscopic animals on which they feed, and also the calcium salts which, incorporated in their skeletons, form the substance of the reef. The living reef is an entity, its varied inhabitants mutually interdependent—for food, for protection, for surface of attachment, and in some cases for exposure to surf or even periodically to the air when the tide retreats. Many animals as well as the calcareous algae add to the mass of the reef, but almost as many destroy it. By mechanical or chemical action the rock is bored by a variety of molluscs, worms, sea-urchins, sponges, and even barnacles, while some plants ramify through the coral rock. Coral fragments are constantly ground smaller by repeated passage through the bodies of *bêches-de-mer*. The sea is the greatest agent of erosion. Crossland [1] maintained that around Tahiti these destructive forces were the greater, and that the reefs were receding, but in many areas they certainly maintain themselves and increase.

The growth and eventual form of a coral reef represents the outcome of a complex of interacting factors—some intrinsic, such as the rate and nature of growth in different corals, others environmental and so extrinsic. Description may suitably begin by consideration of the simplest case, that of fringing reefs. Such formations occur in shallow coastal waters off continents and rocky islands. The initiation of such a reef would follow the settlement of coral larvae, and the formation of the first polyp and skeletal cup, to be followed by others as the colony grew. Growth will tend to be upward towards the source of light. This positive reaction to light has been demonstrated in a variety of ways, most simply by suspending a

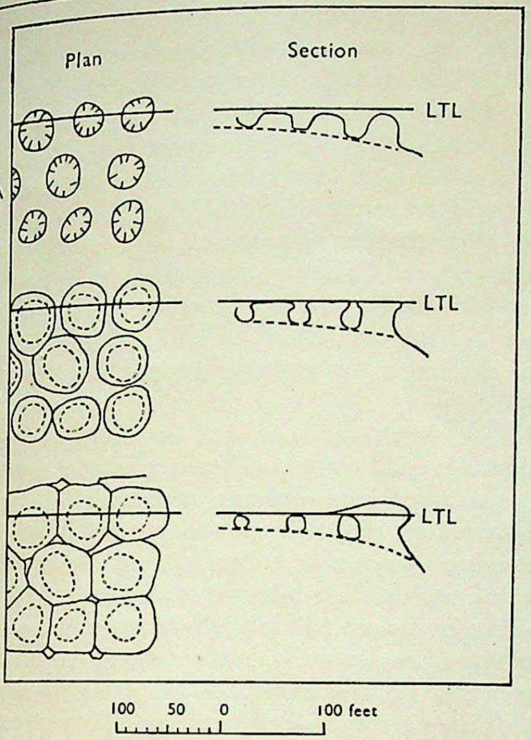


FIGURE 1 – *Bikini Atoll. Diagrams illustrating formation of room and pillar structures on crest of exposed reefs.* A, *bosses of* Lithothamnion; B, *shelving and lateral growth in surf zone;* C, *development of new reef floor, with room and pillar structure below.* LTL, *low tide level.* (*After Tracey, Ladd, and Hoffmeister.*)

broken branch of coral horizontally beneath the surface, when the new growth from the broken end will turn towards the light [2].

Reef-building corals live only in illuminated waters, never much below 25 fathoms. This dependence on light is possibly due to the invariable presence within their tissues of innumerable unicellular brown algae, some 0·01 mm in diameter, known collectively as zooxanthellae. Up to 7400 have been counted within a coral larva 1 mm long. The significance of the relationship between coral and plant symbiont has long been debated, but there is now no doubt that the plants are valueless as food to the corals, being rejected from the tissues, not consumed, when the corals are starved of animal prey [3]. The oxygen produced in photosynthesis by the plants has been claimed to benefit the corals [4], but this remains unproved, the water around corals being usually well oxygenated. However, when building up proteins from carbohydrates, the zooxanthellae utilize all nitrogenous and phosphoric waste, mainly ammonia and phosphates, produced by the corals [3]; hence these, with other end-products of metabolism such as carbon dioxide, are automatically removed from the animal tissues. Corals have no excretory organs, but the plants serve as such, so increasing the efficiency of the corals. This is immaterial to individual coral colonies, which can exist without zooxanthellae, but it may be of vital importance to communities of reef-building corals by conferring those additional powers of growth and repair which permit the establishment and maintenance of reefs.

Whatever the cause, corals grow upward and eventually reach the surface. As they do so, conditions on the two surfaces become increasingly different. Waves approaching a coast are deflected so that they come in at right angles to it. Hence the seaward surface of the growing reef will encounter the incoming swell whereas the landward surface will be bathed by calm but turbid waters. The upper surface, when it finally breaks the surface of the sea, will be exposed to the air when the tide is out. We are thus, as shown in figure 2, presented with a community which, in consequence of its own growth, creates a variety of environments—an exposed seaward surface, a reef crest where the surf breaks, a reef flat behind this, merging where wide enough into a zone of shallow sheltered water where sediment collects. The reef

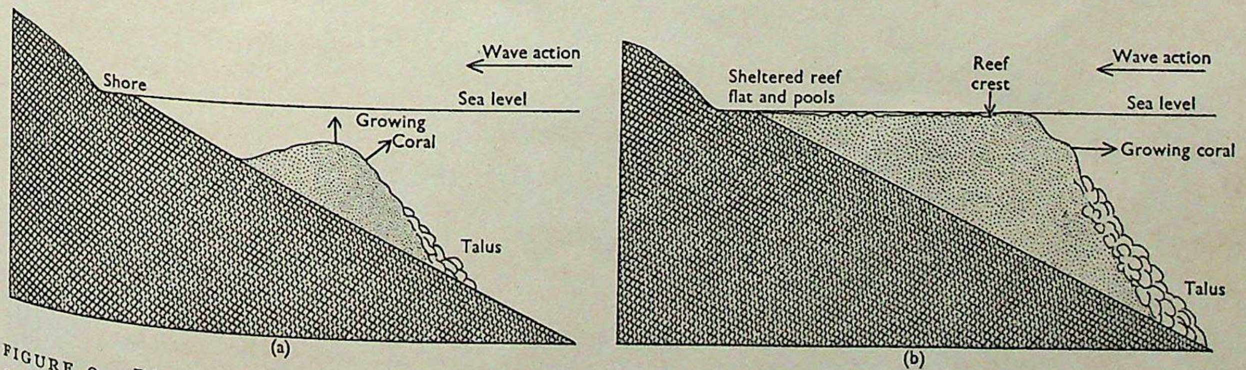


FIGURE 2 – *Diagram showing stages in the formation of a fringing reef.* (a), *mass of coral* (*stippled*) *before reaching surface;* (b), *fringing reef extending seaward.*

crest and flat, and the upper surface of coral masses further inshore, will all experience some degree of exposure.

Thinking for a moment in terms of evolutionary history, we may envisage corals as evolving in shallow seas and not initially forming large colonies. But within the tropics, just possibly owing to establishment of symbiosis with zooxanthellae, vigour of growth increased, great colonies were formed, and the reef-mass eventually reached the surface. Later success might be attributed to adaptation of particular genera or species for life within the different environments that the growth of the reef-mass itself brought into being. This would include acquisition of some of those functional adaptations which enable shore-dwelling animals to withstand extremes of temperature and salinity, and the effect of alternate exposure and submergence.

Modern reef-building corals are so adapted. Some species live only at certain depths below the surface, others can withstand shore conditions, but in varying degrees so that corals occur in zones from below low-tide level upward [5]. Some can withstand the full force of the Pacific surf; most of these have massive skeletons, although branching colonies of *Acropora* also occur [6]. Delicate branching and foliaceous species grow in the lee, while on the *Lithothamnion* ridge live flattened colonies, offering no resistance to the rush of waters. The most specialized corals live free on sand. These include the mushroom coral, *Fungia* [7], with allied genera, and, in the Atlantic, the simple brain coral *Maeandra areolata* [8]. All begin life attached, and then become freed when, at the mercy of water movements, they are deposited with other fragments in the lee and so find themselves on sand. They counter the dangers of this unstable substratum by uncovering themselves when buried, as shown in figure 9, and, at any rate in *Fungia*, by righting themselves if turned over.

Other corals are modified by prevailing conditions. Initially, every difference in coral growth was described as a separate species; later certain field workers, especially Wood-Jones [9], went to the other extreme of claiming that coral species are few, each having many growth forms. Modern opinion lies intermediately; there are many species, but some are plastic, the eventual form assumed depending on the environment. The success of reef-building corals would appear to be due to the existence of some species highly adapted for life in particular environments, and of others which can live under a variety of conditions because they can adapt themselves to them.

The different environments created by the upward growth of a reef are thus occupied. When exposure to the air halts further growth in this direction, the reef continues to increase, most actively along a zone a few fathoms down on the seaward slope. This represents the growing edge, and below it extends a talus of broken fragments. The reef invariably grows out against the force of the waves. Even when an isolated island, such as the extinct volcano of Mer Island in the Torres Strait shown in figure 3, is encircled by a fringing reef, this is much wider on the weather side which faces the south-east trade winds. On the lee of the island, the reef is very

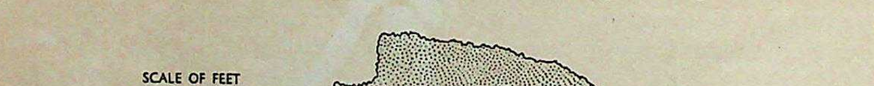


FIGURE 3 – *Outline map of Mer Island, showing much greater extent of fringing reef (stippled) on eastward (weather) side of island. (Modified after Mayor.)*

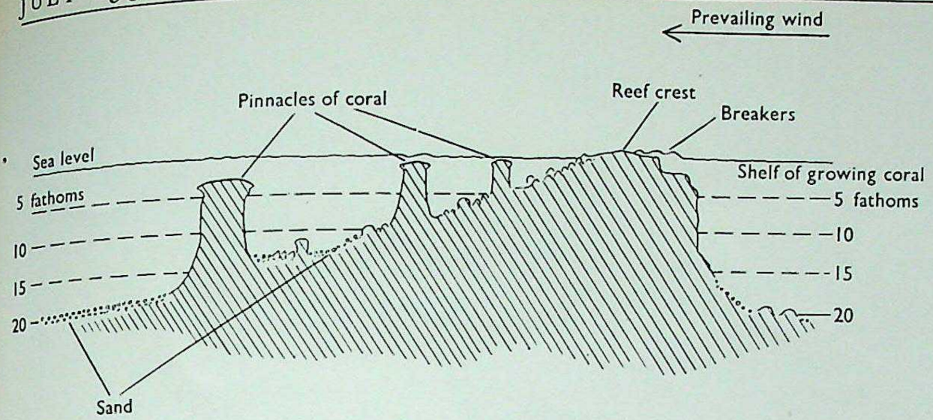

Prevailing wind
Pinnacles of coral
Reef crest
Breakers
Sea level
Shelf of growing coral
5 fathoms
5 fathoms
10
10
15
15
20
20
Sand

FIGURE 4 – *Section through an outer barrier reef, showing relation of form to prevailing winds.* (*Modified after Paradice.*)

narrow and composed of delicately branching stagshorn coral.

Paradice [10] described the orientation of reefs in relation to the prevailing seas in an account of one of the outer reefs of the Great Barrier. As shown in figure 4, he observed the abrupt descent into deep water on the side exposed to the Pacific surf, the shelf of growing coral a few fathoms below the surface, the reef crest cemented with *Lithothamnion*, and the gradual slope on the lee, with the growth there of pinnacles of living coral often mushroom-shaped owing to luxuriant growth at the summit. Between them the bottom is of coral sand. Such conditions were repeatedly encountered during the course of the Great Barrier Reef Expedition, and have been more fully analysed and described elsewhere [6].

Further indication of the forces involved is provided by description of the sheltered island reefs found in the channel between the Great Barrier and the mainland and exemplified by Low Isles, the headquarters of the Great Barrier Reef Expedition. As shown in figure 5, the reef is oriented in relation to the south-east trades. The seaward side is convex, is consolidated but with no *Lithothamnion* ridge, and descends quickly into deep water. On the lee it is concave, with a protected anchorage, while a small sand cay (insular bank) is formed from material which is carried over or swept around the reef. Off-shore are many coral pinnacles (figure 8) arising from water of slowly increasing depth. The general picture resembles that for barrier reefs, but the seas, owing to protection within the barrier, are much slighter. Possibly for this reason, material thrown on to the surface of island reefs accumulates there, and a variety of formations occurs, each comprising some type of calcareous debris and all moulded by the exclusive action of wind and waves. It is maintained by many that only after elevation, or fall in sea level, can material accumulate on the surface of a reef, but some measure of shelter is also essential. Sand cays never occur on outer barrier reefs, but may do so on inner reefs.

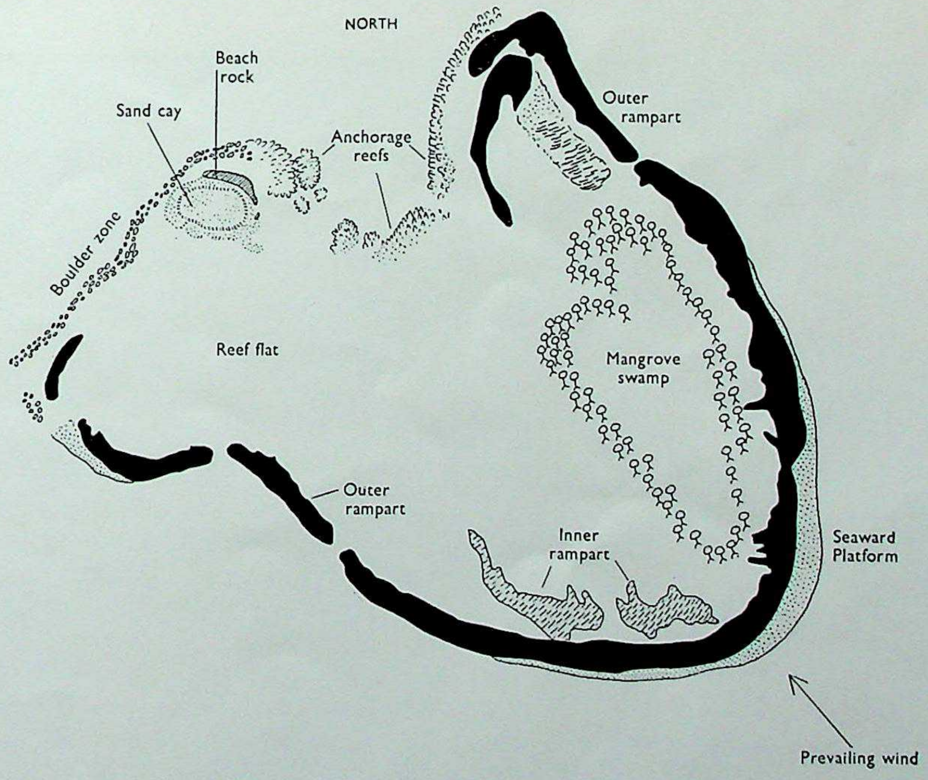

NORTH
Beach rock
Sand cay
Anchorage reefs
Outer rampart
Boulder zone
Reef flat
Mangrove swamp
Outer rampart
Inner rampart
Seaward Platform
Prevailing wind

FIGURE 5 – *Low Isles, North Queensland. Outline map, showing form of the reef and the various formations built up on its surface.* (*After Stephenson* et al.)

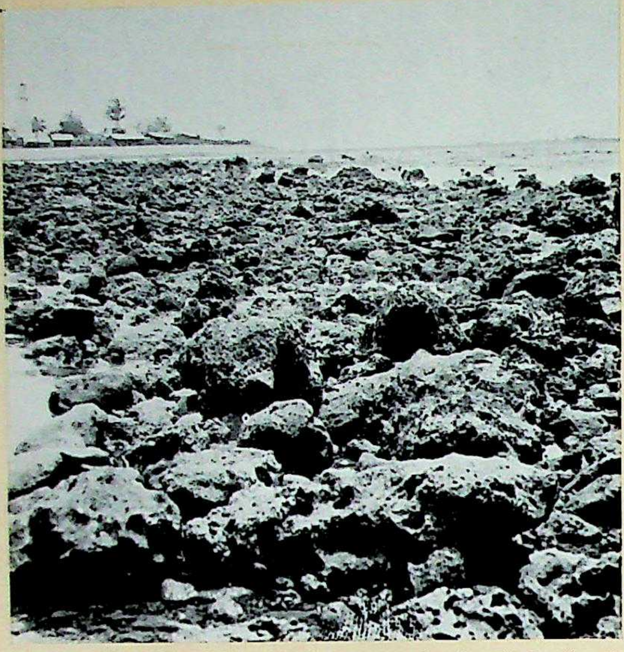


FIGURE 6 – *Low Isles. North-west margin of reef, showing, in foreground, boulder zone (exposed at low tide); in background, the sand cay.*

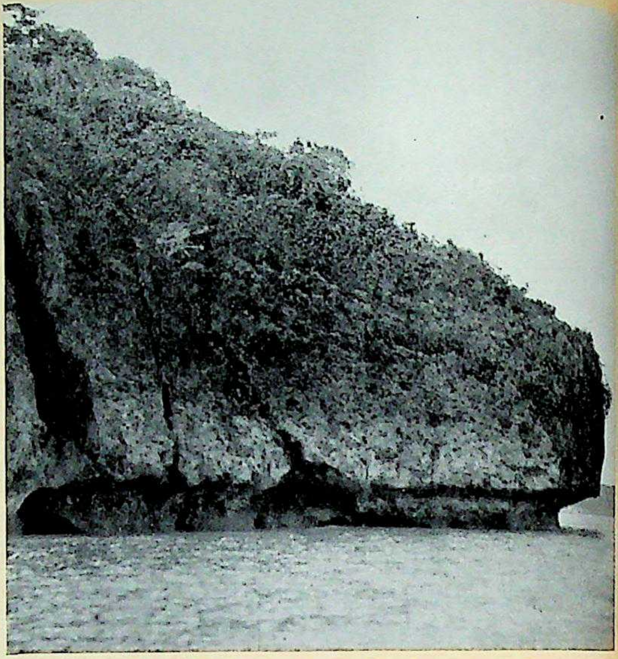


FIGURE 7 – *Vavau, Tongan Islands. Elevated coral rock, showing its solution by the sea between tidemarks.*

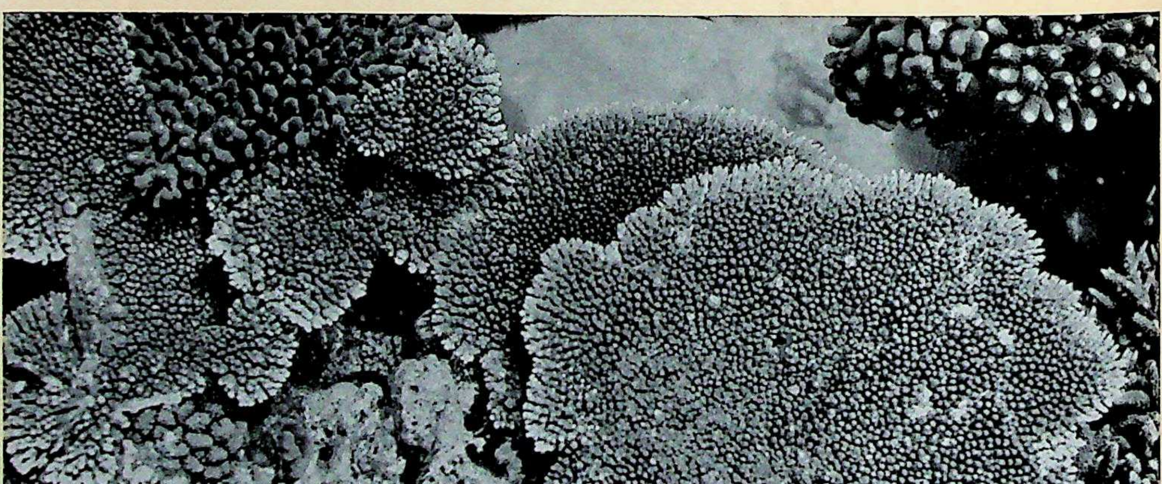
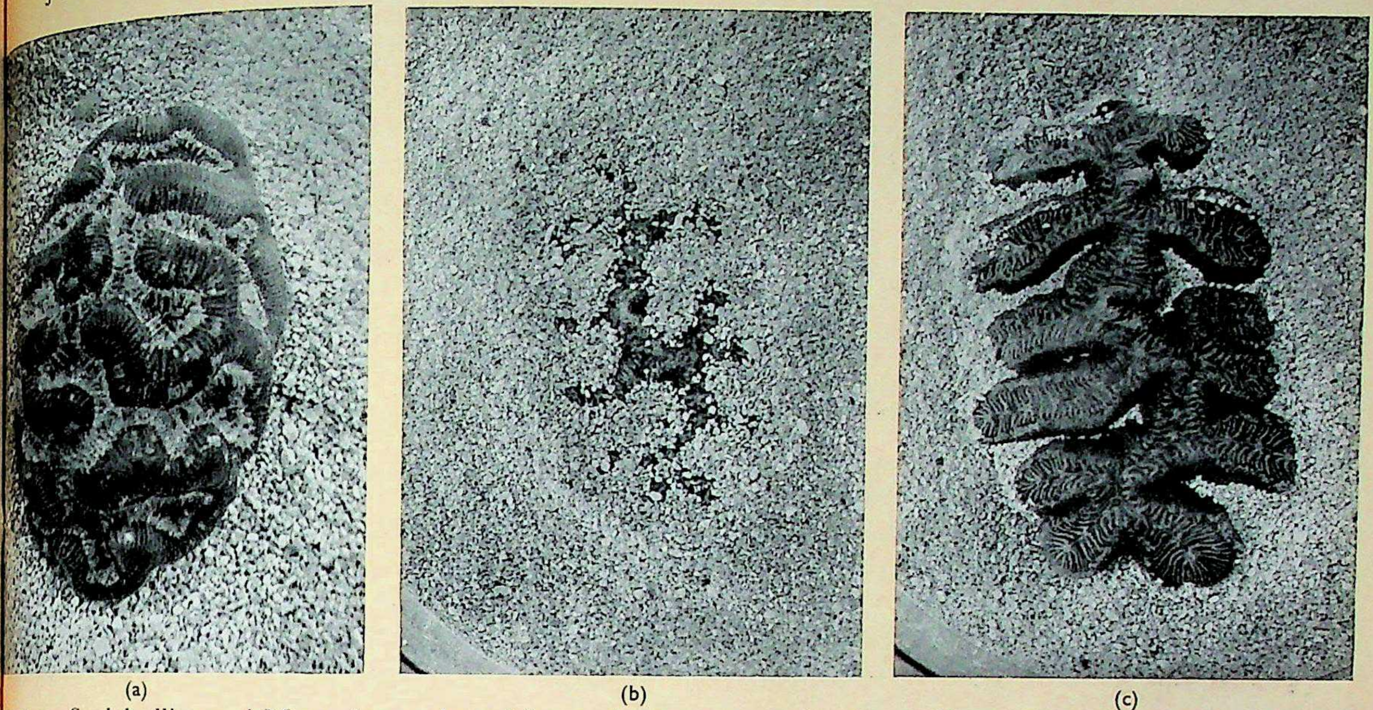


FIGURE 8 – *Summit of a coral pinnacle growing in sheltered water, showing branching coral extending laterally, so producing mushroom form.*



RE 9 – *Sand-dwelling coral,* Maeandra areolata. (a), *normal appearance on surface of sand;* (b) *and* (c), *stages in emergence after being* *d with sand.*

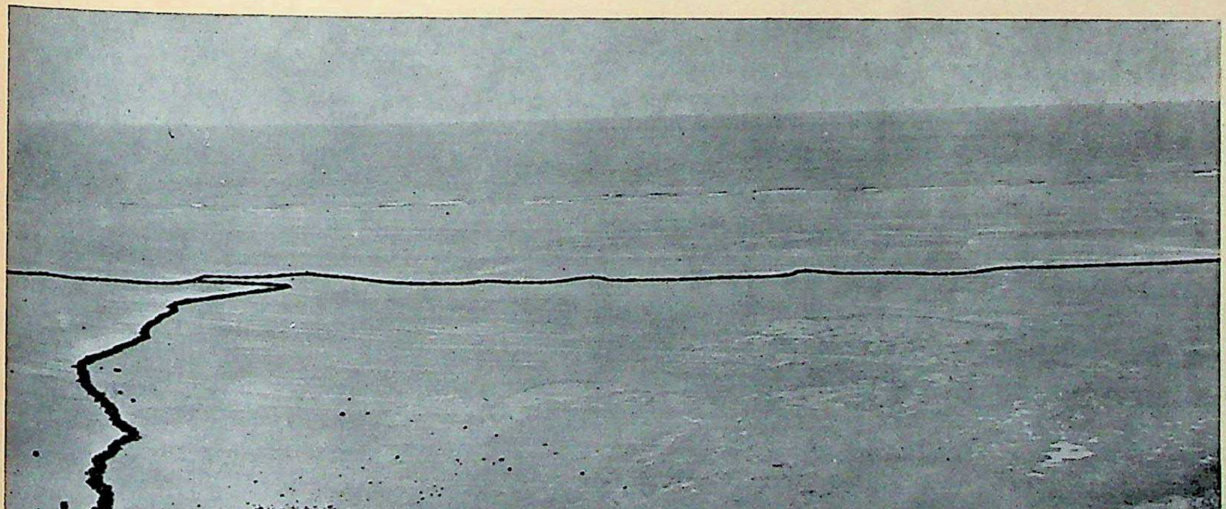


FIGURE 10 – *Mer Island, showing fringing reef* (*see figure* 3), *and reef crest with* Lithothamnion *ridge lying beyond wall of native fish traps.*

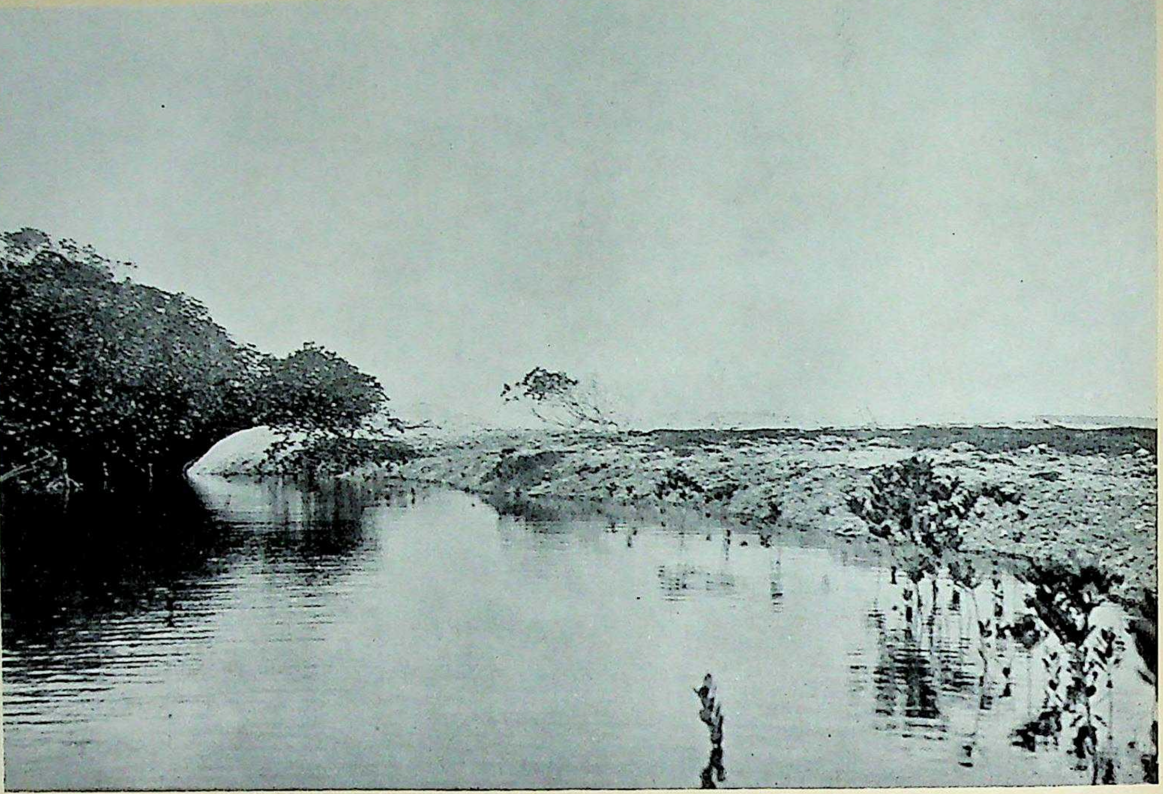


FIGURE 11 – *Low Isles. Escarpment of inner rampart with protected moat and mangrove trees in its lee.*

Parallel to the seaward margin, coral fragments accumulate to form a succession of ramparts. Each slopes gently seaward, but has the steep inner escarpment shown in figure 11. Since the original survey of Low Isles in 1928–9 [6], further surveys in 1934 [11] and 1945 [12] have recorded how the ramparts first described have been pushed further over the reef, while a new one has been formed (figure 12). Within the shelter of ramparts, mangrove trees grow, and an extensive swamp covers much of the reef surface.

Where shelter is insufficient for mangroves, the surface of the reef exposed at low tide consists of a flat, with living coral in pools and within a moat formed behind the outer rampart (figure 5). Along the north-west margin, that is on the sheltered side, masses of coral rock form the conspicuous boulder zone shown in figure 6. This consists of the remains of the pinnacles of coral which grow off-shore. Unlike the corals of the exposed face of the reef, which grow under the continuous restraint of powerful seas, these pinnacles grow up in sheltered water. Hence they become unstable, and are broken off and thrown on to the surface of the reef by cyclonic seas that from time to time strike the reefs from northerly directions during the summer. Such tracts of boulders are found only within the cyclone belt, being absent in the East Indies [13] and in the Torres Strait. On the inner side of the crest of outer barrier reefs there is a zone of smaller boulders, but it is uncertain whether these have a similar origin, coming from the lee, or whether they have been carried, like the smaller fragments that form ramparts, over the reef-crest.

Calcareous debris thus collects as shingle rampart, boulder, and sand. The first is maintained by interlocking of fragments, the second by unaided weight, the third by the formation of layers of beach rock around the base of the sand cay. This rock consists of sand particles cemented by calcium carbonate, and it buttresses the sand cay during the summer when it might be washed away by northerly storms. Ramparts, boulders, and sand are all continuously being worn away by exposure to wave action and to the air, and also by dissolution between tidemarks. This dissolution, which does not affect submerged rock, is well

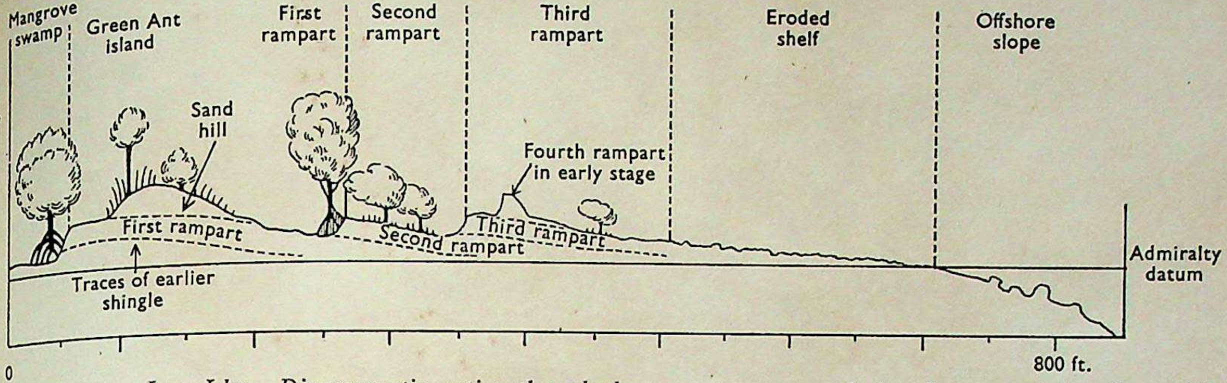


FIGURE 12 – *Low Isles. Diagrammatic section through the rampart system, vertical scale exaggerated* 5 *times. The fourth rampart has been formed since* 1929. (*After Fairbridge and Teichert.*)

evidenced around elevated coral islands where, as shown in figure 7, the sea cuts a deep groove. All destruction is at least equalled by new growth of coral.

Similar effects of prevailing weather on the form of reefs have been recorded by Dutch workers in the East Indies [13], and have been observed by the author at the Tortugas Keys in the Gulf of Mexico. They are no less striking on atolls, purely coral formations remote from any land, about which our knowledge has been much extended by recent American work at Bikini and adjacent atolls in the Marshall Islands [14]. The features already noted on barrier and island reefs occur here, though modified owing to the great and now encircling force of the sea. What probably correspond to the two ends of the exposed face of a barrier reef have been bent round to enclose the sheltered lee, the whole forming a great oval. The outer ring of reefs is not everywhere the same. Reefs exposed to seas driven by the north-east trade winds are affected by the immense force of the surf that breaks continuously upon them, and *Lithothamnion* grows thickly (figure 13, *L*). As on Funafuti Atoll [15], and also on the weather side of exposed reefs off the south of Java [13], the *Lithothamnion* extends seaward in a series of spurs with intervening grooves which run inward as deep surge channels. Isolated masses of calcareous algae may grow up, become mushroom-topped, and fuse with one another above, leaving channels below. Openings into these channels form blowholes, through which water is forced high into the air. Details of the formation of these 'room-and-pillar' structures are given in figure 1. The effect of the surge channels is most effectively to dissipate the force of entering seas. Exposed surfaces on more protected reefs within the Great Barrier are serrated.

Marginal reefs on the sheltered western side of Bikini, not exposed to such constantly heavy surf, show evidence of some erosion as a result of summer changes of wind. Embayments, often with contained boulders, are formed by collapse of portions of the reef margin. The reefs that fringe the lagoon are more sheltered on the north-east, and more exposed to seas generated by wind blowing over the lagoon, on the south-west, and they are correspondingly modified in form, though to a much smaller degree than the outer reefs. The lagoon is full of coral knolls which rise from its floor, often almost to the surface, and vary in diameter from tens to hundreds of feet. Within the 24-mile-long lagoon of Eniwetok Atoll, 180,000 soundings revealed over 2000 coral masses [14]. Although often very much larger, they probably correspond to the pinnacles in the lee of barrier and island reefs. Within the shelter of lagoons they can seldom suffer such destruction.

Given an isolated submarine platform, no matter

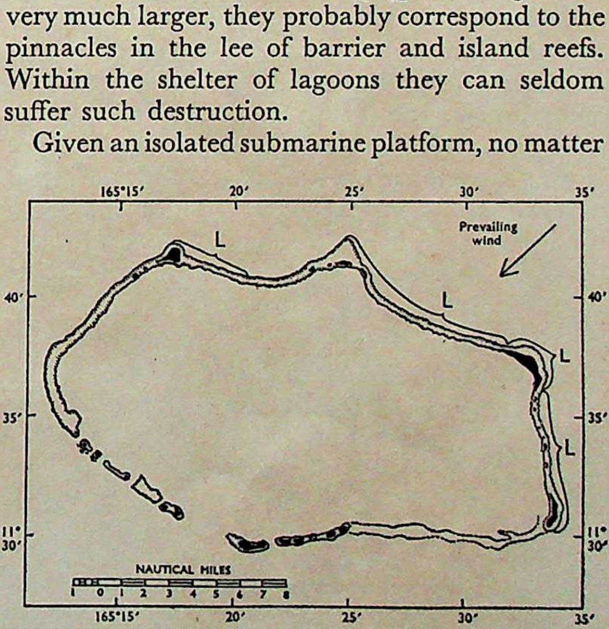


FIGURE 13 – *Bikini Atoll. Outline map, showing arrangement of reefs with islands* (*shown black*) *surrounding central lagoon.* L, *fully exposed marginal reefs with* Lithothamnion *ridge.* (*Modified after Tracey, Ladd, and Hoffmeister.*)

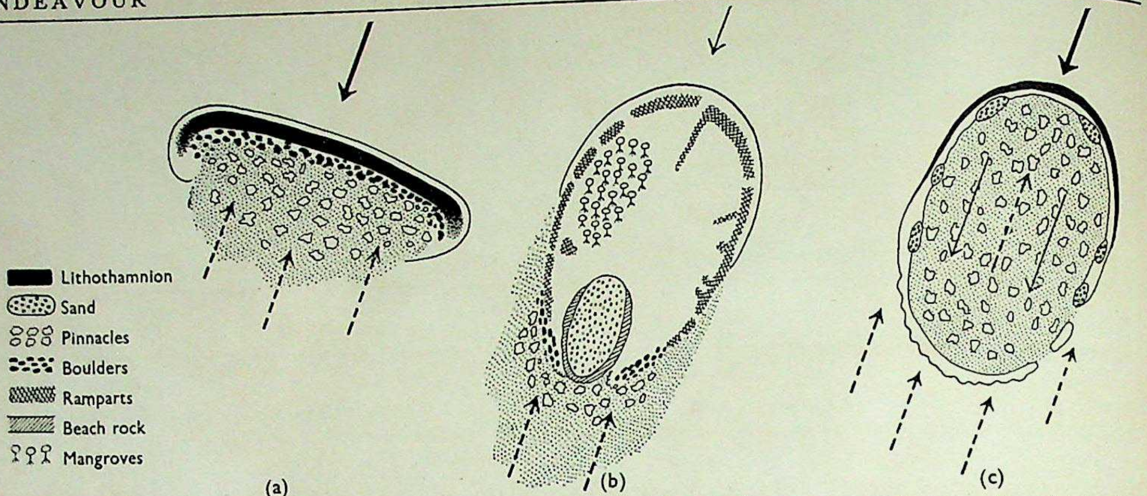


FIGURE 14 – *Diagrams of* (a), *Barrier Reef;* (b), *Island Reef* (*without anchorage, more typical than Low Isles*); (c), *Atoll. Unbroken arrows indicate direction of prevailing winds and, by their thickness, strength of seas which they generate. Reef surfaces on windward side with compact,* Lithothamnion *ridge on* (a) *and* (c) *where seas are very powerful. Broken arrows indicate course of winds and approximate strength* (*very variable*) *of seas causing erosion of the unstable coral growth on the lee side. Shallow water indicated by shading.*

whether subsiding or stationary, within the zone of coral growth the constant movement of the sea will, as outlined for fringing reefs, influence the form of the upward-growing reef. Conditions will be most favourable around the margin of the platform, even the lee of which is bathed with clear water. As marginal coral growth increases, so water movements within will diminish, turbidity will increase, and sediment will be deposited. In this sheltered water certain types of coral will form the characteristic pinnacles. This process can be envisaged as continuing until the marginal reefs, initially no doubt on the weather side, reach the surface. Negative displacement of sea level may then precede the accumulation of sand to form islands, later vegetated. The permanence of these islands, however, may be due to shelter on the side facing the lagoon, over the restricted extent of which no storm, from any direction, can raise seas comparable in force with the oceanic surf outside.

Whatever element of truth there be in these speculations, the fact remains that all reefs show clear evidence of the moulding action of wind and weather, both below and above tidemarks. In figure 14, the most characteristic features of an exposed barrier reef (*a*) are compared with those of a sheltered island reef (*b*), and both with those of an atoll (*c*). In the last, although peripheral exposure is as great as, or greater than, that experienced by a barrier reef, internal shelter is ensured because the reefs encircle a central lagoon.

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Antibiotics and microbial antagonism in plant pathology

ERNA GROSSBARD

Although the use of antibiotics in controlling human disease has been one of the most important medical developments of this century, their use in controlling bacterial diseases of plants has hitherto been far less closely studied. There are, however, important possibilities in this direction, on the one hand by direct application of specific antibiotics, and on the other by stimulating, by appropriate manuring, the growth of micro-organisms, naturally present in soil, which produce antibiotics. The outlook seems favourable.

Man's very existence is determined by the activities of the soil microflora. Members of this complex community are among the most important factors in food production, by fixing atmospheric nitrogen, and by acting as agents in the never-ending conversion of plant and animal residues into plant nutrients and, consequently, into human food. Recent researches show that to these beneficial properties may be added the power of soil micro-organisms, such as actinomycetes, bacteria, and fungi, to manufacture potent antibiotics; penicillin, streptomycin, chloromycetin, and aureomycin are well-known examples.

Throughout the whole range of properties which characterize antibiotics we meet with the principle of specificity. Antibiotic action is selective. Only certain groups of micro-organisms are sensitive to one given antibiotic. Strain specificity applies also to the production and concentration of these inhibitive agents. While one strain of a species may be very efficient, another may fail to yield the desired antibiotic. There is specificity as regards the composition of the culture medium and environmental culture conditions. Some factors affecting stability are specific. Some antibiotics are toxic to plant and animal tissue, others may damage plant tissue but not affect that of animals. The mode of action of antibiotics varies considerably; it consists in a subtle interference with certain individual cell reactions of sensitive micro-organisms. This interference more often results in inhibition of growth rather than in a straightforward lethal action. Antibiotics sometimes have the power to lyse (dissolve) microbial tissues. Though themselves manufactured by micro-organisms, antibiotics prevent infection by, and multiplication of, many other micro-organisms responsible for disease in man, animals, and plants.

The diversity in formation and action of antibiotics derives from the variation in their chemical composition. Moulds and actinomycetes are the most prolific sources of antibiotics. While many mould-produced antibiotics are organic acids, such as aspergillic, gladiolic, mycophenolic, or penicillic acids, antibiotics obtained from actinomycetes (such as streptomycin) tend to have basic properties. Many antibiotics manufactured by bacteria are polypeptides, e.g. subtilin. One species may give rise to one or more antibiotics. On the other hand, one and the same compound may be formed by several different organisms.

ANTIBIOTICS FOR THE CONTROL OF PLANT DISEASES

The problem of using antibiotics for plant protection may be approached from two different angles. The materials may be used in a purified and concentrated state as sprays, dusts, and seed or soil disinfectants, or their action may be exploited indirectly on the basis of biological control by microbial antagonism.

Very little published information is as yet available on the value of antibiotics for plant protection. Much of the work is centred round those materials which have given good results in human therapy. The majority of plant pathogenic bacteria are Gram-negative. As streptomycin is active against both Gram-positive and Gram-negative bacteria, extensive tests were made with this antibiotic, with considerable success. Examples of plant-pathogenic bacteria which are highly sensitive to streptomycin include species of *Xanthomonas* and *Pseudomonas*, causing a variety of leaf-spot diseases of the cucumber, bean, tomato, and stone fruits; *Bacterium carotovorum*, the soft-rot agent of many root crops; *Bacterium tumefaciens*, responsible for crown gall; and *Corynebacterium michiganense* (exceptional as a Gram-positive plant pathogen). Streptomycin is one of the few antibiotics to have found practical application. It has been used with success as a seed-dressing against bacterial canker of the tomato (*Corynebacterium michiganense*), and as a very effective controller of crown gall. Crown gall is a disease of a variety of plants, especially those which are propagated by grafting. Galls are formed by a process assumed to be somewhat analogous to that of tumour formation in animals. It is for this reason that much research is at present being carried out, especially as regards antibiotic action, on both the causative organism, *Bacterium tumefaciens*, and the tumourous tissue. In field trials penicillin also has been tested. Cotton-wool wrappers soaked in the crude or second-grade preparation of the antibiotic were placed round the aerial galls, or the roots and crown of dormant plants were immersed in the solution, or the material was injected into the stem. It is claimed that not only was the disease arrested but that the tumours already formed were destroyed and eventually dried up (figures 5–7). Streptomycin was more efficient in action than penicillin. There is some disagreement as regards the effect of the antibiotics on tumour tissue. Workers who have used the purest preparations of the antibiotics available, studying the problem in tissue cultures, did not observe regression of tumour tissue. Such disagreement of results is not infrequent, and may be explained by the fact that materials were not standardized. This probably applies to the somewhat contradictory reports on actidione, the only antifungal agent known to be produced by *Streptomyces griseus*. While some plant pathologists claim that they have obtained a very good protection of beans from mildew (*Erysiphe polygoni*) by spraying the plants with actidione at concentrations of 5 parts per million, without any injury to the plants, others report serious phytocidal effects.

Many human diseases are of bacterial origin, and the antibiotics used in human therapy are consequently antibacterial. The great majority of plant diseases, however, are caused by fungi, and it is therefore essential that plant pathologists should isolate materials which are primarily antifungal. Investigations on these lines have led to the preparation of a variety of antifungal substances. Examples are gliotoxin and viridin, both isolated from the green mould *Trichoderma*; gladiolic acid from *Penicillium gladioli*, a parasite of gladioli corms; griseofulvin, frequentin, and a red pigment from various soil *Penicillia*; musarin from an actinomycete inhibiting *Fusarium oxysporum cubense*; and antimycin from an unidentified species of *Streptomyces*. Gliotoxin was tested as a seed-dressing, but although it inhibited several pathogens of cereals, the concentrations required and the costs of production are too high to render it more suitable as a seed-dressing than the organo-mercurials used at present. The results of experiments recently carried out in Britain with griseofulvin are very encouraging. It has been convincingly demonstrated that this antibiotic has the properties of a systemic fungicide. It was taken up by the roots and translocated throughout the plant, protecting it to a considerable degree against infection. Lettuces were grown in nutrient solutions containing griseofulvin, and tomatoes were raised in sand cultures watered at intervals with this antibiotic; the lettuces were inoculated with *Botrytis cinerea* and the tomatoes with *Alternaria solani*. The treatment with griseofulvin considerably reduced disease incidence in both crops. An immunity of 74 per cent. was recorded for the tomato plants. Though still in the experimental stage this work is of great importance, because it opens up new roads in the field of chemotherapy in plants. Systemic fungicides are known, but their number and range of activity is small. Antimycin, isolated in the United States and tested extensively in greenhouse trials, may be regarded as a promising antibiotic fungicide. It inhibits germination and growth of *Venturia inaequalis* (a fungus causing scab on apples and pears) and a variety of other plant pathogens. It has the merit of not causing any injury to the plant. When artificial rain was applied, antimycin retained its activity for a considerable time. It can be used together with the routine sprays of insecticides without becoming inactive. These examples serve to show that in the not too distant future antibiotics may become a useful source of new types of fungicides. One of the greatest obstacles to be overcome is the high cost of production of these new materials. It has, however, been possible to synthesize chloromycetin on a commercial scale, and it is hoped that other antibiotics may be produced in this sometimes more economical manner. For plant protection, the cheaper second-grade or crude product can frequently be used with good results.

MICROBIAL ANTAGONISM

There is a mode of disease-control in which the principle of antibiotic action may be utilized without involving great expense.

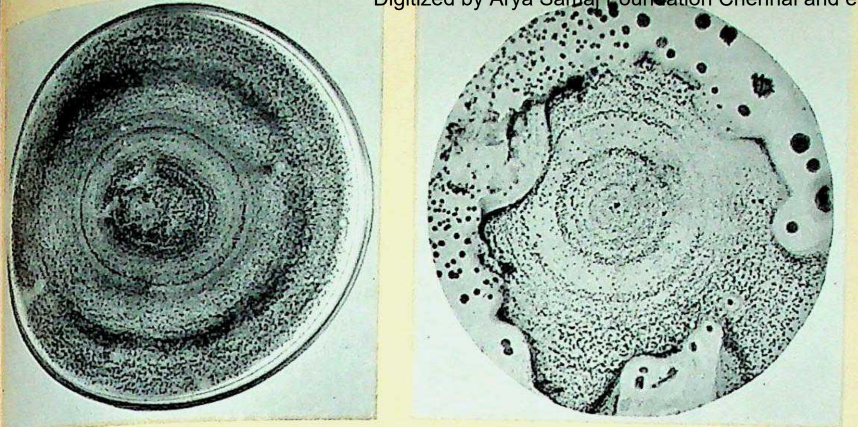

(a) (b)

FIGURE I – *Example of competition between* Colletotrichum atramentarium, *a tomato parasite, and two other micro-organisms. In* (a) *growth of* C. atramentarium *is unaffected, but in* (b) *an abnormal colony has resulted.*

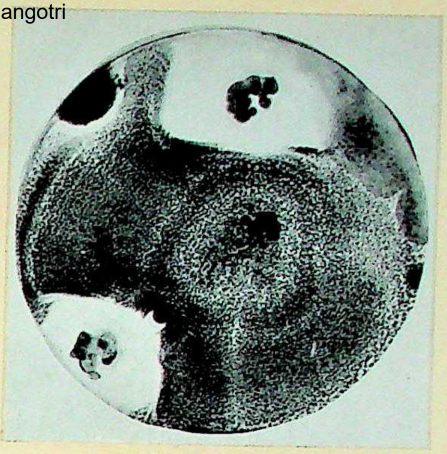


FIGURE 2 – *This culture of* C. atramentarium *has been inoculated with four other micro-organisms, but only one, an actinomycete inoculated at two opposite points, has proved antagonistic.*

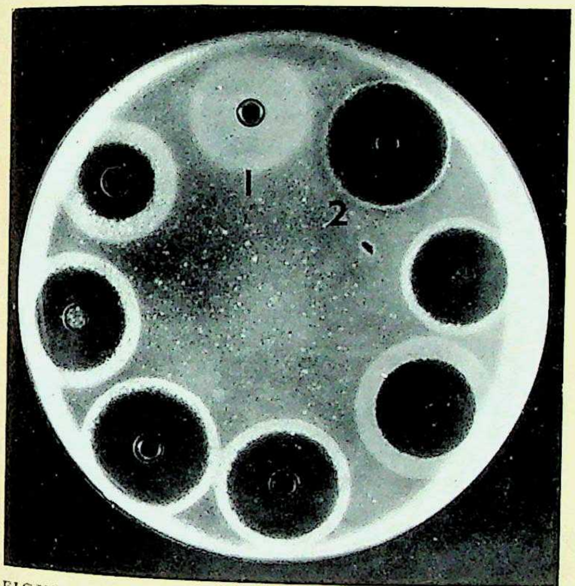


FIGURE 3 – *Assays, by the cylinder plate method developed for penicillin, of fluids from soils inoculated with* P. patulum, *and manured with various sources of carbohydrate. The test organism is a soil bacillus.* (1) *is fluid from uninoculated soil;* (2) *contains a solution of expansine* (*patulin*).

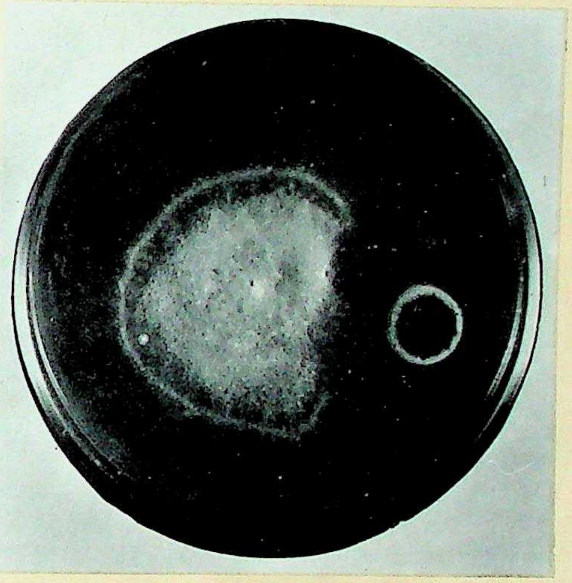


FIGURE 4 – *Disintegration of hyphae of a fungus causing 'damping-off' by an antagonistic micro-organism introduced after the fungus had established itself.*

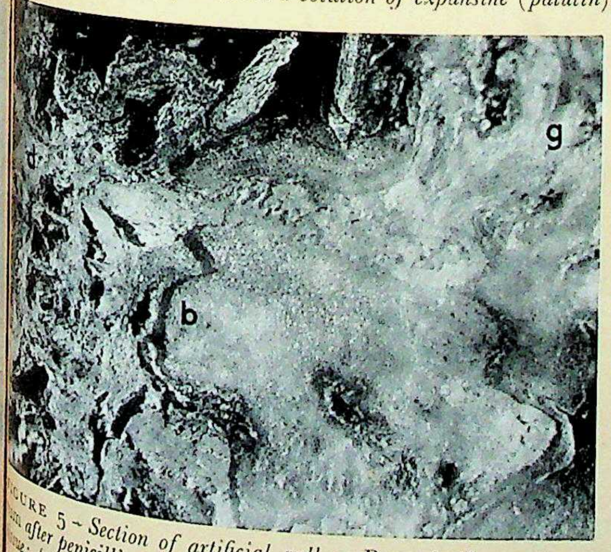


FIGURE 5 – *Section of artificial gall on* Bryophyllum pinnatum *after penicillin treatment.* (d) *Dead gall tissue;* (b) *healthy tissue;* (g) *untreated, active gall tissue.* (*By courtesy of Prof. J. G. Brown.*)

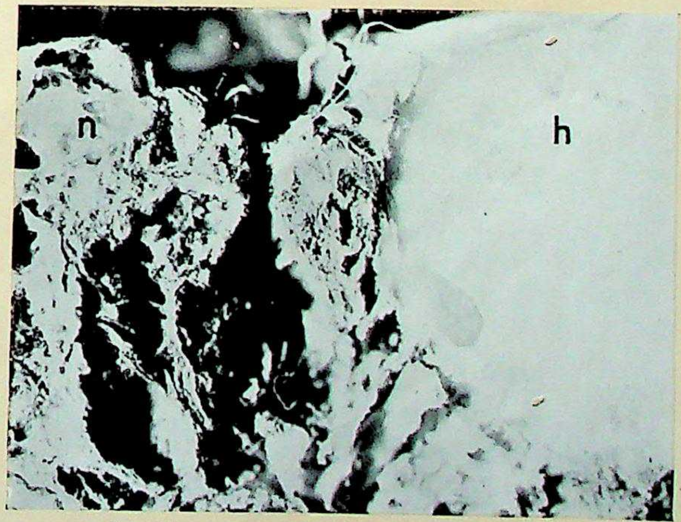
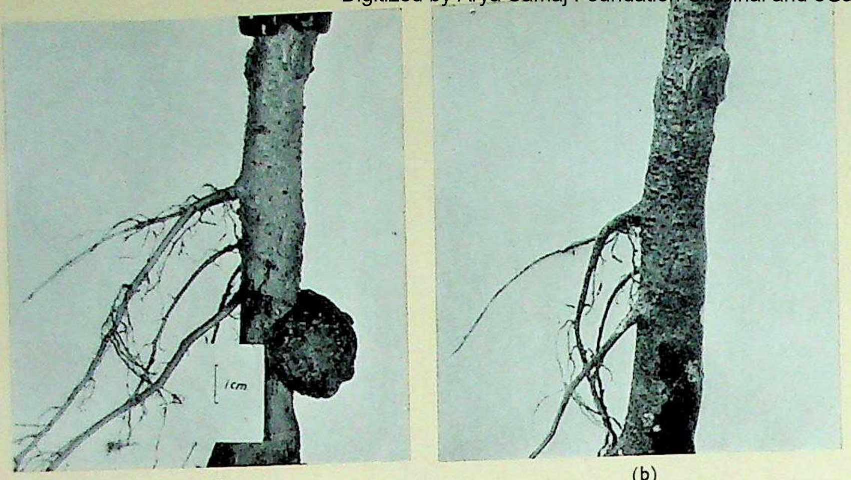


FIGURE 6 – *Transverse section of artificial gall after streptomycin treatment. Gall tissue at* (n) *is dead and disintegrating, but untreated tissue* (h) *is unaffected.* (*By courtesy of Prof. J. G. Brown.*)



(a) (b)

FIGURE 7 – *Effect of treating crown gall on greengage with penicillin:* (a) *before treatment,* (b) *eight weeks later.*

(*By courtesy of Prof. J. G. Brown.*)

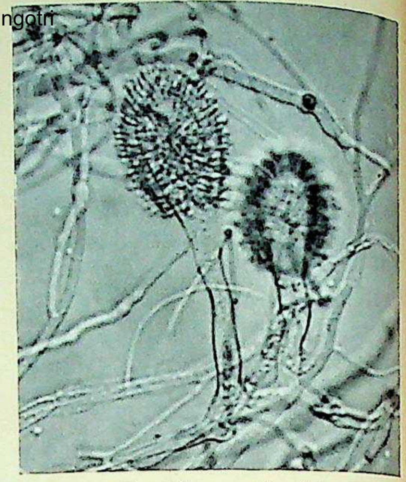


FIGURE 8 – *Photograph of* Aspergillus clavatus. *This species forms expansine (patulin) on standard laboratory media; when grown on organic manures or on soil it also produces an antibiotic.*

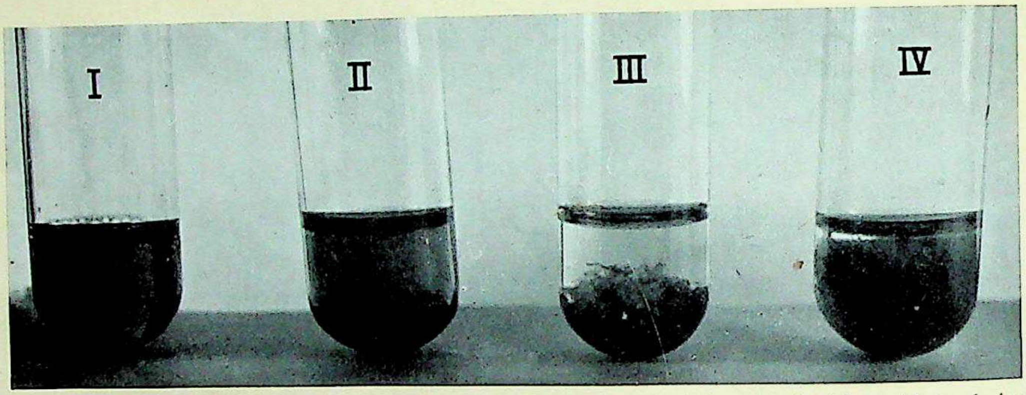


FIGURE 9 – *Inhibition of the parasite* Phytophthora *by extracts of soil inoculated with moulds producing antibiotics. The soils were inoculated with (I)* P. patulum, *(II)* A. terreus, *and (III) an unidentified mould. (IV) is a control.*

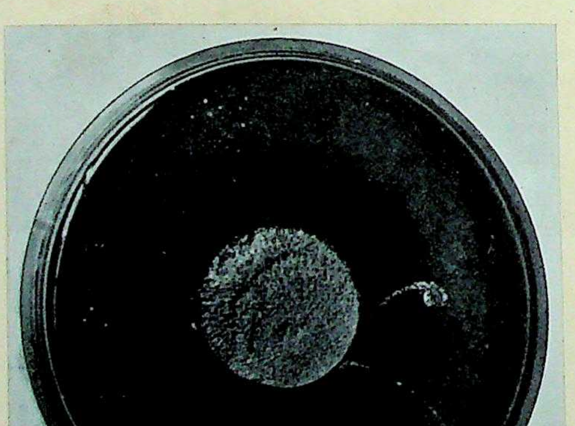


FIGURE 10 – *Inhibition of growth of* Bacterium carotovorum, *a soft-rot organism, by a disc of* A. clavatus *inserted in agar inoculated with the bacteria. The active substance produced is expansine (patulin).*

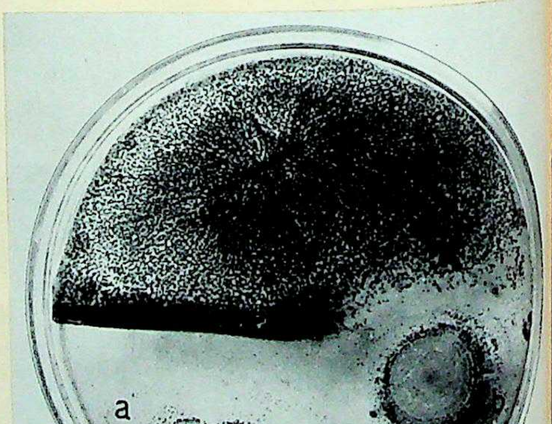


FIGURE 11 – *Inhibition of* Colletotrichum atramentarium *by* (a) *a strongly antagonistic* Penicillium *and* (b) *a weakly antagonistic* Penicillium.

graphs, except figures 5–7, by J. E. Morton and H. T

In mixed cultures, one or a group of micro-organisms may be inhibited by the activities of another; this is termed microbial antagonism. An interesting application of it to disease-control has been investigated in Britain. Lettuces are frequently attacked by the grey mould *Botrytis cinerea*, and many micro-organisms are antagonistic to *Botrytis*. It has been possible to colonize moribund tissues of lettuces, usually found on the lower leaves, with antagonistic organisms. Subsequent infection by *Botrytis* of plants cultivated in frames was considerably reduced. This kind of method of preventive control seems very promising.

MICROBIAL ANTAGONISM AND ORGANIC MANURING

Attempts to control plant diseases by the mechanism of microbial antagonism refer chiefly to root diseases. It has been found empirically that many soil-borne parasites are suppressed by heavily manuring the infected soils with organic matter. The classical work carried out in Britain was the control of potato scab by incorporating large quantities of green manures with the soil. In Arizona and other cotton-growing areas, the serious cotton root-rot disease (*Phymatotrichum omnivorum*) was successfully controlled by putting large quantities of hay and other manures into deep furrows. Canadian workers were able to eradicate strawberry root-rot and scab of potatoes by ploughing in a crop of soy-beans. The basis of these control measures is a modification of the soil microflora, and a stimulation of a mode of microbial activity antagonistic to certain parasites. By the incorporation of plant and animal residues, new types of micro-organism are introduced which are chiefly saprophytes, living on dead matter only. They may have been present already in a particular soil, especially as ungerminated spores. The additional food-supply encourages their development and antagonistic activity.

Canadian scientists, working on the control of strawberry root-rot and potato scab, have applied several types of manure, such as red clover, rye grass, and soy-beans. Though the first two effected a shift in the microbial balance, only soy-beans controlled the disease. A similar result was obtained when glucose or similarly rich sources of carbohydrate were applied. It was concluded, therefore, that the type of decomposition, in this case the carbohydrate breakdown, is an important factor. The parasite *Ophiobolus graminis*, responsible for a disease of cereals aptly named 'take all,' can be eradicated by the use of manures of a high carbon but low nitrogen content. It is thus not sufficient to employ merely organic matter: the choice of an appropriate material is essential.

In the mechanisms of microbial antagonism many factors are concerned, such as competition for food; an excess of carbon dioxide; and the formation of toxins. The question now arises—are such toxins antibiotic substances, and is there a correlation between organic manuring and the formation of antibiotics in the soil?

ANTIBIOTICS IN THE SOIL

Many of the micro-organisms which produce antibiotics on standard laboratory media were isolated from the soil. While the soil can be regarded as their natural habitat, it does not necessarily follow that the antibiotics associated with them will be formed on so poor a medium as is furnished by soil alone. It has been suggested that manuring might supply additional nutrients to induce antibiotic formation directly in the soil. Experiments in Britain have shown that certain saprophytes which are known to produce antibiotics on laboratory media will form an inhibitive agent when grown on materials, frequently employed in agriculture as manures, such as straw, timothy, and bracken, which have been sterilized. It can be argued that organic manuring not only modifies the microflora but stimulates antibiotic formation in the soil. This hypothesis is supported by results of other experiments initiated in Britain. Antibiotic activity against plant pathogens such as *Phytophthora parasitica* (damping off), *Thialviopsis basicola* (tobacco root-rot), and *Bacterium carotovorum* was demonstrated in soil centrifugates prepared from either partially or completely sterilized soils inoculated with one of several fungi which produce antibiotics on standard laboratory media. This effect was, however, dependent on the presence of an additional carbohydrate source in the soil. This suggested that apart from carbohydrates, which can be supplied by manuring, the soil can be regarded as a suitable medium for antibiotic production, at least by certain fungi. The part antibiotics can play in microbial antagonism is also dependent on the length of time antibiotics retain their activity in the soil. Though it has been shown that some antibiotics, especially those of a basic nature, are adsorbed by colloids, workers in Britain demonstrated that some antibiotics persisted in the soil for a considerable time, and that activity was retained longest in soils of the same type as that from which the fungi were originally isolated. Although no claim has yet been made that a material was extracted from soils which could be identified chemically as one of the known antibiotics, there is strong evidence to suggest that antibiotics are present or may be established in certain soils. It is also significant that requirements essential for the control of certain soil-borne pathogens are similar to those necessary for antibiotic production in the soil under controlled conditions—namely, materials high in carbon and low in nitrogen content. Furthermore, it has been demonstrated by very sensitive extraction methods that extracts from natural soils which were not inoculated with any specific organisms, but treated with glucose or a similar carbohydrate, displayed antibiotic activity.

Practical applications of these findings have been attempted. Soils partially sterilized, according to practices established in nurseries, were inoculated with an antagonist of the damping-off parasite *Phytophthora parasitica*, and these soils were manured with various sources of carbohydrate in an attempt to control damping-off of tomato seedlings. After incubation the parasite was introduced and seeds were sown. During the period of treatment the soil became rapidly recontaminated and could be no longer regarded as partially sterilized. The results obtained showed considerable variations, an experience frequently observed in work on microbial antagonism. The spread of the disease from a centre of infection was considerably reduced when sugar-beet pulp was employed as a manure. While the addition of straw, or straw plus glucose, frequently gave similar results, these treatments often stimulated rather than controlled damping-off. Experiments were carried out with *Rhizoctonia solani* on lettuces. In sterile soil, the incidence of disease was considerably reduced, but in the field the treatment was ineffective.

Many reports are current that certain pathogens have been suppressed by the inoculation of soils with antagonistic cultures without the addition of any nutrients. This work was initiated by the control of *Rhizoctonia solani*, causing damping-off of citrus seedlings, by inoculation with *Trichoderma spp.*, but in this case a change of soil conditions was carried out by acidification. 'Take all' was controlled by adding antagonists to the soil. Similar reports come from Russia as regards cereal diseases; from India in relation to cotton wilt; and from France in respect of the control of wilt of melons and the sclerotinia disease of sunflower.

The outstanding feature of these results was that control was very effective in sterilized soil, but less effective or not significant in non-sterile soil. As regards natural, unsterile soil, reduction of disease and increase in growth-rate is reported from the West Indies, where fields infected with Panama disease received bulk inoculation of antagonistic actinomycetes. This indicates that under certain conditions the soil, as such, without further adjustments, supports growth of antagonists and stimulates antagonistic activity. However, in general it appears that satisfactory results in controlling plant pathogens are more likely to be obtained by manuring the soil in addition to the introduction of antagonistic organisms, especially in unsterile soil.

There is an unwieldy mass of data available on the above mode of control. Comparisons are difficult, as the materials and strains of pathogens and their respective antagonists were not standardized. Failure and success have been reported. The difficulties with which pathologists are faced here are very similar to those which had to be solved before the introduction into certain soils of efficient strains of nodule bacteria on legumes was possible. Land on which it was formerly impossible to grow leguminous crops successfully, because of the absence of an efficient strain of the nodule bacterium which fixes atmospheric nitrogen, now supports a good crop when the seeds are dressed with a specific strain of the nodule bacterium.

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Water in the architecture of plants

T. A. BENNET-CLARK

Water is of great importance as a structural material in plants. The maintenance by plants of an excess hydrostatic pressure—which keeps them rigid much as air keeps an inflated tyre rigid—poses an important question, for there must exist a mechanism by which flow of solute is maintained against the concentration gradient. In consequence energy is used up, and it must be concluded that plants work continuously merely to keep themselves erect.

Architecture may involve study of styles and construction. It must also include study of the properties of building materials, and it is this latter aspect of plant architecture with which we are here concerned.

The water in a plant may be compared in its relevant structural importance with the compressed air in a pneumatic tyre. The structural water is indeed compressed to surprisingly high pressures inside the cells of most plants. The analogy with pneumatic tyres is rather close, and in both tyres and plant cells the rigidity of the structure is determined jointly by the elasticity of the cover and the excess pressure of the gaseous or fluid contents.

Recognition of the structure and mechanism of this building unit of the plant has been achieved very slowly. Robert Hooke observed the subdivision of the plant body into compartments which he termed cells, but it was not until Moldenhawer (in the first decade of the nineteenth century) devised the technique of maceration that the structure of a mass of similar cells became clear. These groups of cells had been called tissues by Nehemiah Grew in his great work on plant anatomy, and that term, in current use in the biological sciences today, enshrines the fact that he did not recognize the separateness of the walls of individual cells but thought that the fabric of cells was a woven structure like lace.

The recognition of the protoplast or primordial utricle as a lining to the cell wall marked the next advance, but it was not until much later in the century that clear conceptions emerged regarding the status of the water, protoplast, and wall of a typical plant cell.

The classic work of the great plant physiologists Dutrochet, Pfeffer, and de Vries not only provided the student of the living plant with much of the information that he required, but has had immense repercussions in the field of pure chemistry; it represents probably the most important 'reciprocal lend-lease' between botanists and chemists. Dutrochet first observed the phenomenon, and coined the term osmosis. Pfeffer's determinations of osmotic pressure at different temperatures and concentrations provided the data from which van't Hoff developed the theory of dilute solutions, and de Vries's recognition of the abnormally large osmotic pressures of electrolytes helped to pave the way, in the hands of Arrhenius, for the concept of ionic dissociation.

This is the historical reason why many text-books of physics and of chemistry contain diagrammatic pictures of a plant cell. A cell or tissue of cells which is relatively rigid is described as turgid; those which have been plasmolysed are flaccid. Plasmolysis is due to water passing from the central cavity or vacuole into the external medium; this is not associated with passage outwards of solutes from the vacuole. These appear to be retained, and the protoplast, or more precisely the vacuolar membrane, has therefore been regarded as a semi-permeable membrane.

There has been little emphasis on the remarkable character of the phenomenon of plasmolysis. It implies the absence of adhesion of protoplast to cell wall, or, if the external layer of the protoplast is adherent, it would seem that some internal layer concentric with it is readily sheared. This, however, seems unlikely, for the protoplast shows little or no sign of injury as a result of being prised away from the wall.

One must clearly attempt to estimate the magnitudes of these hydrostatic pressures of contents of plant cells if one is to discover anything about the methods by which they are produced and maintained.

Two types of method can be used to obtain estimates of the excess hydrostatic pressure of the contents of plant cells. The procedures are illustrated diagrammatically in figure 1. The

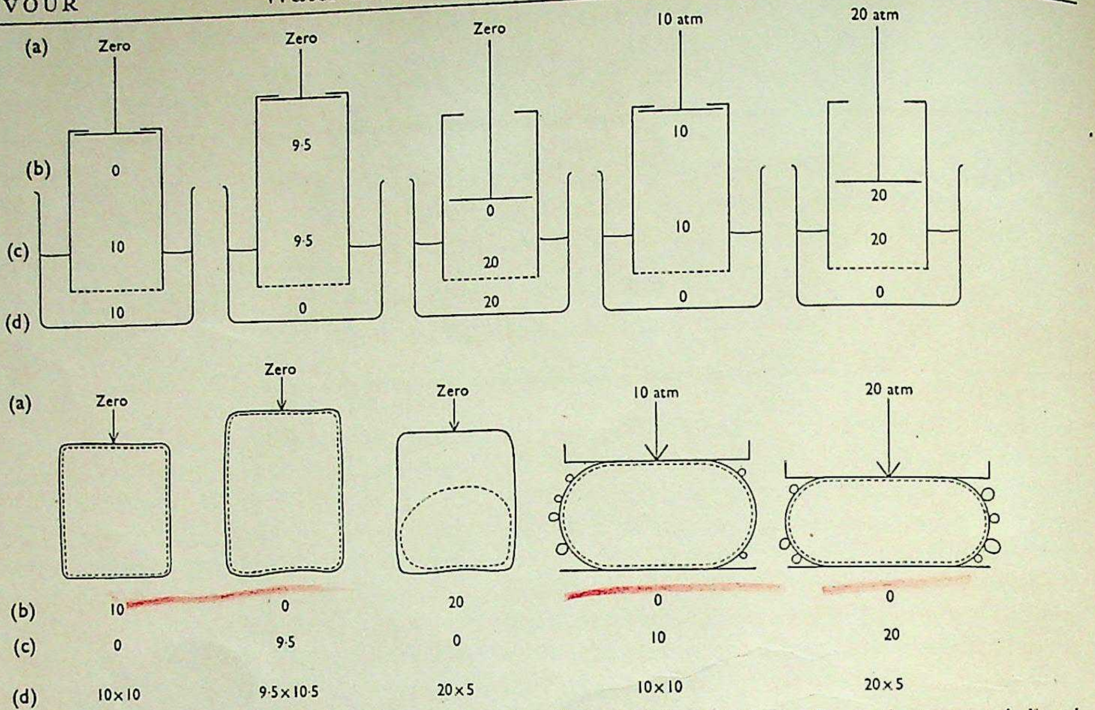

FIGURE 1 – (*Upper part*) *Cylinders with semipermeable end-walls, containing solutions of osmotic pressure indicated, immersed in other solutions. Figures indicate* (a) *excess pressure above atmospheric applied to the pistons*, (b) *excess internal hydrostatic pressure*, (c) *internal osmotic pressure, and* (d) *external osmotic pressure.* (*Lower part*) *A plant cell treated in the same manner as the cylinder represented immediately above. Figures indicate* (a) *excess applied pressure*, (b) *external osmotic pressure*, (c) *wall pressure, which equals internal excess hydrostatic pressure*, (d) *internal osmotic pressure × vacuolar volume. Note that compression causes exudation of drops of water pressed out of the vacuole.*

lower diagrams represent a living cell immersed in solutions of 10, zero, and 20 atm osmotic pressure and subjected to mechanically applied pressures of 10 and 20 atm respectively. This cell is represented as having expanded about 5 per cent. in volume when the wall is stretched by the maximum hydrostatic pressure (9·5 atm) which the cell contents can generate on immersion in pure water. The upper diagrams represent the behaviour of a cylinder having a semipermeable end-wall, so constructed that it elongates somewhat when an excess internal pressure forces the piston against the stop-ring at the top of the cylinder. The unstressed cylinder is supposed to be completely filled with a solution of 10 atm osmotic pressure (the solute being one which does not pass through the semipermeable membrane).

The cylinder is shown immersed in solutions of osmotic pressure 10 atm, zero, and 20 atm, and with excess applied pressures to the piston of zero, 10, and 20 atm. The curve in figure 2 shows the relation between excess applied pressures as abscissae, and percentage of the total water pressed out as ordinates. The cylinder and cell wall are represented as stretching so that the volume is about 5 per cent. above their unstressed volume when the internal excess hydrostatic pressure equals 9·5 atm. The graphical record thus shows that about 5 per cent. of the internal water is pressed out by an applied pressure of 10 atm. Larger applied pressures than this push the piston down into the cylinder, pressing out the volumes of water indicated graphically.

If one assumes that PV is a constant, one can obtain the initial hydrostatic pressure of the cylinder or cell contents from graphical records of the type shown. Extrapolation of the curve *AB* to the zero ordinate gives the hydrostatic pressure when the piston is about to be pushed in from the stop-ring. The ordinate of *B* is an estimate of the extensibility of the cylinder. If the extensibility of the cylinder or the cell is very small, in other words if the points *B* and *C* nearly coincide, the abscissa *DC* is a direct measure of the hydrostatic pressure of the contents.

Figure 3 shows the relation between the volume expressed and the applied pressure in the case of beech leaves, where in this experiment *B* and *C* were nearly coincident. This coincidence is not invariable, but it is not uncommon in thin leaves. One can also determine the external osmotic pressure

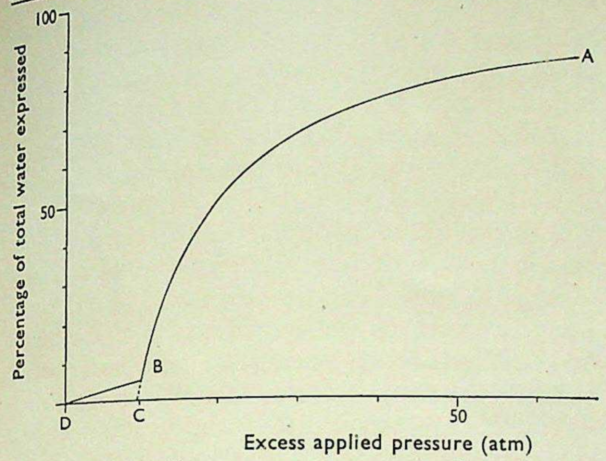

FIGURE 2 – *Ordinates show percentage of total water pressed out of cylinders or cells such as those of figure* 1 *by the excess applied pressures, shown as abscissae.*

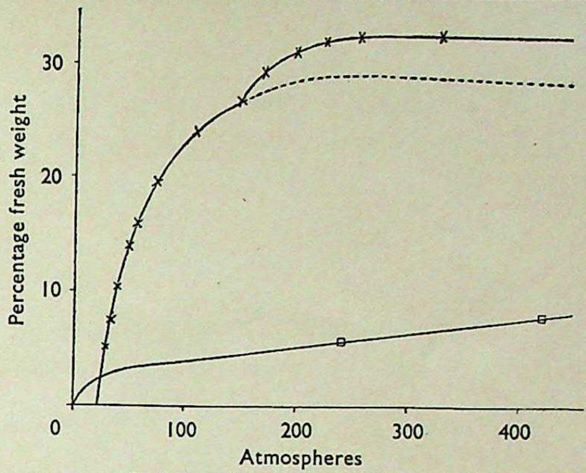

FIGURE 3 – *Volumes of juice expressed by small pressure increments from leaves of* Fagus sylvatica*; living leaves —x—; killed residue from fully pressed living leaves —□—.*

(*By courtesy of* The New Phytologist.)

required to cause the protoplast just to contract away from the wall. This osmotic pressure should theoretically be equal to the pressure indicated by the abscissa of *C* in figure 2. Within the limits of the considerable experimental errors this was found to be so [1].

One has, then, some confidence in the determinations of the hydrostatic pressure of cell contents in a number of cases, whether the direct mechanical pressure method or the plasmolytic method has been used. The plasmolytic method had been used as early as 1880 by de Vries, but recent work has shown the existence of a remarkably large difference between the estimate of internal hydrostatic pressure based on the plasmolytic method and the actual osmotic pressure of the expressed juice, and, as the latter has most usually been found to be considerably less, the true significance of the plasmolytic estimate is naturally called in question.

The agreement between the plasmolytically and mechanically determined hydrostatic pressure is therefore significant. It had been thought that the hydrostatic pressure was developed in cells solely as a consequence of the difference in activity of water inside and out, as in the model cylinders of figure 1. Though this view is still held by many workers, it is not by any means certain that it is completely correct.

A feature of the high hydrostatic pressures in plant cells, that seems to be little emphasized in the earlier researches, is that it implies that the living protoplasts do work in pumping material into the cell to produce the excess pressure in the first instance, and to maintain it against leakage afterwards.

The real problem of the architecture of plants is how this work is done, and what fraction of the energy made available in respiration is used in this manner.

One might describe as the simple osmotic view the hypothesis that the sole mechanism consists of the accumulation of electrolytes and non-electrolytes inside the vacuoles of cells against a concentration gradient. That this occurs is amply supported by many investigators. The most striking instances are noted in the case of electrolytes, where penetration inwards is observed even when the internal concentration of the solute is as much as 400 times the external.

This clearly would cause a lower activity of water inside the vacuole than outside, were it not that some simultaneous inflow of water causes a rise of hydrostatic pressure. The system envisaged is really a dynamic equilibrium in which any leakage of solute from the internal solution is made good by active secretion, and in which an excess hydrostatic pressure is built up equalling the osmotic pressure of the internal solution, thus causing the activity or chemical potential of water to be equal on both sides of the cell membrane.

The important point to elucidate is the mechanism of solute uptake or secretion against a concentration gradient. In recent years, a number of significant findings has been made. The uptake has been shown to be closely linked with aerobic respiration (Steward, Hoagland, and others). Uptake of salts was shown to be associated with an increase in rate of respiration above what has been termed the ground-respiration; this extra salt-respiration is cyanide-sensitive, and the suggestion has been made that it is linked with a cytochrome system.

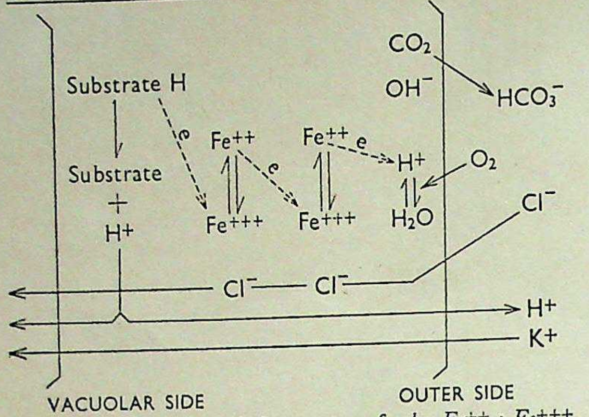

FIGURE 4 – *Scheme of electron transfer by* Fe^{++} : Fe^{+++} *system (possibly cytochrome) coupled with ion exchanges (somewhat modified from Robertson and Wilkins* [6], *Crane* et al. [2], *and Lundegårdh* [4]).

Still more recently, the very important finding has been made by Robertson and his co-workers that a stoichiometric relation exists between the salt-respiration and salt-uptake, when the external concentration of salts is high enough not to be limiting the rate of uptake. Under these conditions, the uptake of 4 anions is associated with consumption of 1 molecule of oxygen.

The importance of this finding in relation to recent work on the mechanism of secretion of hydrochloric acid by gastric mucosa, and to Lundegårdh's suggestions regarding the mechanism of salt-uptake, has been the subject of several recent papers.

A result of fundamental importance is the finding by Rehm [5]; Crane, Davies, and Longmuir [2]; and others, that the ionic composition of the phases on the two sides of certain isolated secretory membranes, such as gastric mucosa of the frog, had little effect on the potential difference across it. Korr [3] had already pointed out that the oxidation-reduction potential in the system:

$$\mathrm{Hg\ HgCl}\left|\mathrm{KCl}\right|\begin{matrix}\mathrm{Fe^{++}}>\\ \mathrm{Fe^{+++}}\end{matrix}\left|\underset{\xrightarrow{\quad e \quad}}{\mathrm{Metal}}\right|\begin{matrix}\mathrm{Fe^{++}}<\\ \mathrm{Fe^{+++}}\end{matrix}\left|\mathrm{KCl}\right|\mathrm{HgCl\ Hg}$$

can be measured if a metallic (electron-transferring) membrane is placed between the two redox systems as shown.

Lundegårdh had suggested that an electron-transferring array consisting of an oxidizing enzyme-complex could act as a mechanism of anion uptake, though it was hardly possible to get direct evidence in favour of his view. Crane *et al.* [2], and Robertson and Wilkins [6], have elaborated this view and suggest a scheme such as is shown in figure 4.

A point of some interest in the behaviour of gastric mucosa is that the onset of secretion is associated with decrease in potential difference between secretory and nutrient side of the membrane. The independence of the membrane potential difference from *p*H and other ion-concentration differences suggests that this potential difference is caused by oxidation-reduction potential differences on the two sides of the membrane, and that an electron-transfer mechanism exists—that the membrane is in fact a type of semi-conductor.

In a normal-sized parenchyma cell of a plant, the high internal hydrostatic pressure makes the problem of determining potential differences between vacuole and external medium one of great difficulty. It is, however, apparently the case that tissues immersed in a medium such as distilled water, and free from external supply of ions, show a rather marked discrepancy between plasmolytically and cryoscopically determined osmotic pressure, which suggests that active secretion of water is taking place. This condition of absence of salt-secretion might, from analogy with behaviour of mucosa, be expected to bring about a greater potential difference across the cell membrane, and thus to promote increased electrosmotic flow of water inwards or maintenance of an excess 'active pressure' by electrosmosis.

Though there is still much uncertainty as to whether water is actively secreted, perhaps electro-osmotically as suggested above, there is no doubt that the high excess hydrostatic pressures of plant cells are generated and then maintained by active secretory processes, either of solutes or, less certainly, of water.

Interference with the normal processes of respiration are at once accompanied by outward diffusion of solutes and reduction of the internal excess hydrostatic pressure on which the mechanical strength and rigidity of the tissues depend.

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Underground gasification of coal

H. ROXBEE COX

Gas produced by the underground gasification of coal is unlikely to be suitable for domestic purposes owing to its comparatively low calorific value. It could, however, be used for heating and for power generation. Underground gasification offers the advantage of a means of exploiting coal seams which are too poor or too narrow to be worth mining in the ordinary way. It has yet to be proved whether or not the process is economically attractive, but its possibilities are such that it is being investigated in a number of countries, including Britain.

There is an extensive literature [1] on the underground gasification of coal, the greater part emanating from Russia, where considerable progress seems to have been made. Elsewhere in the world work has been begun, and results achieved in that part of it done outside Britain have been reported [2–8]. While, therefore, a brief reference will be made to the work done in other countries, the main purpose of this article is to give a brief account of what has recently been done in England. This work will be fully dealt with later elsewhere, in papers written by the men who have been in charge of it on the spot. To these detailed papers the present article may be regarded as a brief introduction by one whose responsibility was to initiate the present series of experiments.

Reduced to its simplest terms, underground gasification means heating coal while it is still in the coal seam, in such a way that gas is produced which can be brought to the surface and used there. This can be done in a variety of ways, and the method to be adopted on a particular site must always be largely dictated by the local conditions. For the purpose of illustration it is perhaps simplest to consider first the elementary system shown in figure 1. This diagram indicates that two holes have been drilled vertically downwards from the surface until they reach a seam of coal, and that another hole has been made more or less horizontally in the coal seam joining the bottoms of the two vertical holes. If a fire is started in the coal, and air is pumped down one of the vertical shafts, then so long as the fire is burning we may expect to find hot gas coming up the other vertical bore-hole.

In effect, what we seek to do is to start in a small part of the coal a small fire, the gases from which will be sufficiently hot to maintain continuous gasification of the rest of the coal, but will not contain sufficient oxygen to permit its complete combustion. It is clear, therefore, that the air supply must be correctly controlled if the gas coming to the surface is to have a calorific value as well as sensible heat. If too much air is supplied, the coal will be completely burned underground, and though we should then get hot flue gases, the heat of which could be turned to good account, they would in general be less convenient to use than a gas which can be burned.

A system such as that in figure 1 could be produced by underground working, but other ways

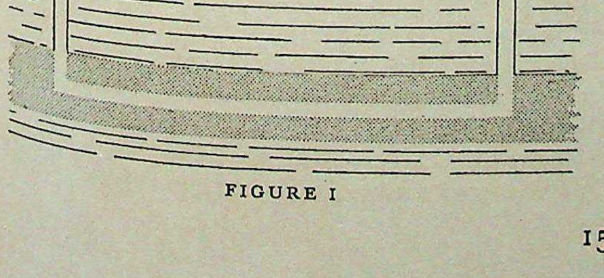

FIGURE 1

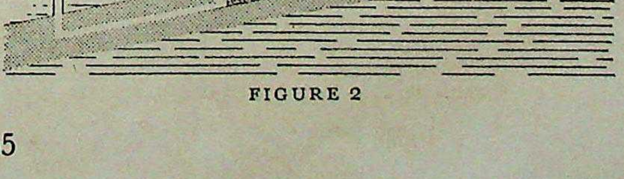

FIGURE 2

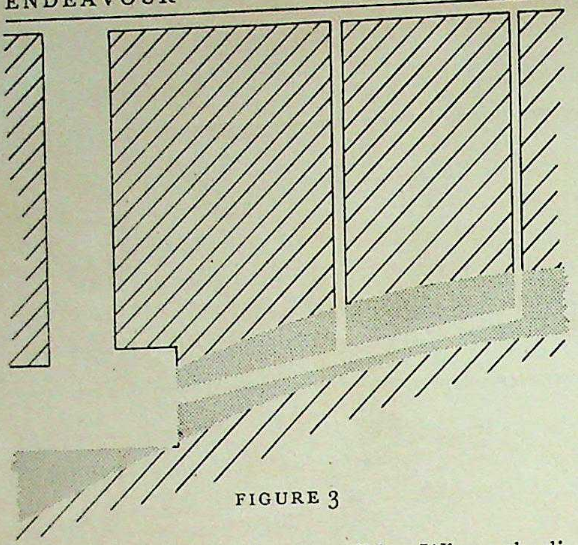

FIGURE 3

of doing it are sometimes possible. Where the lie of the land and the run of the coal seams permit, it is possible to drill the verticals from high ground, and to put in the horizontal by drilling from an external surface, as indicated in figure 2. A variation of this arrangement, when there is coal available in the vicinity of a disused mine, is to make a horizontal drilling from an abandoned working, as indicated in figure 3.

It is not difficult to imagine that in a large-scale undertaking there would be a number of systems, of the type shown in figure 1, with their upcasts connected to form a supply of power gas to electrical generating plant. I use the words 'power gas' advisedly, because it is very improbable that the gas produced would have a calorific value high enough to permit it to be used for domestic purposes.

Behind the foregoing simple descriptions there is the tacit assumption that the coal seam to be gasified is lying more or less horizontally. Frequently, however, coal seams dip steeply, and, when they do, a rather different system can be used if desired. Figure 4 shows a portion of a steeply dipping seam in which two shafts lying entirely in the coal have been mined from the surface. The bottoms of these shafts, as before, are joined by a more or less horizontal mined shaft. If gasification is imagined to have started in the shafts, it is easy to visualize that the whole of the coal bounded by the shafts—indicated by the full lines in the figure—will ultimately be gasified. An even simpler system, which could be made entirely by drilling, would be obtained if the two shafts from the surface were so directed as to intersect.

The work now in progress on a modest scale in Britain is part of a programme of scientific research and experiment designed to exploit to the full the indigenous fuel resources of the country. It is imperative to use coal resources as economically and as completely as possible. This does not mean only that we must burn coal in the most efficient way. It means also that we must try to use sources of energy which have not hitherto been exploited. There is a great deal of coal in Britain in seams of quality so poor that they are not worth mining. In other words, the price likely to be obtained for the coal does not justify the cost of getting it to the surface. The possibility of obtaining energy from this coal *in situ* is obviously of great interest.

There is also coal left in the region of disused mines. This coal may be of good quality, but for a variety of possible reasons, such as the extreme narrowness of the seam in which the remaining coal lies, it has ceased to be an economic proposition to mine it. It is possible that underground gasification might turn this unmined coal into a useful source of energy.

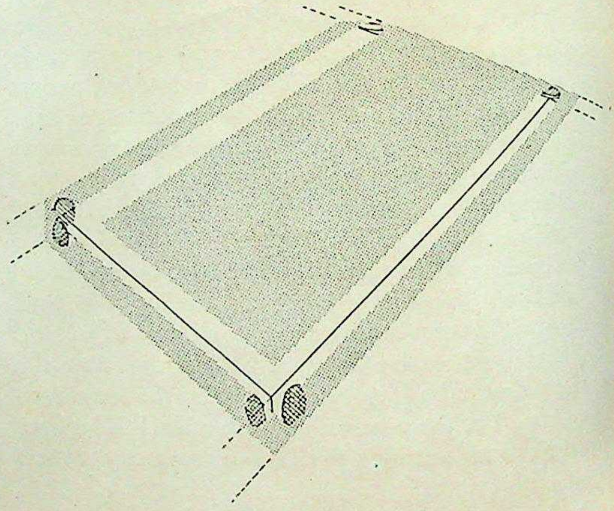

FIGURE 4

Finally, there is coal so deep in the earth that the cost of reaching it, and of overcoming the difficulties of working at the high temperatures which exist several thousand feet below the surface, makes mining it extremely expensive. Perhaps this coal may one day be exploited by underground gasification methods; at the present time, however, this possibility is little more than an interesting speculation, and the technical obstacles to be overcome before it can be achieved—if ever it can be—are formidable.

One can scarcely avoid the idea that if poor or narrow coal seams can be economically exploited

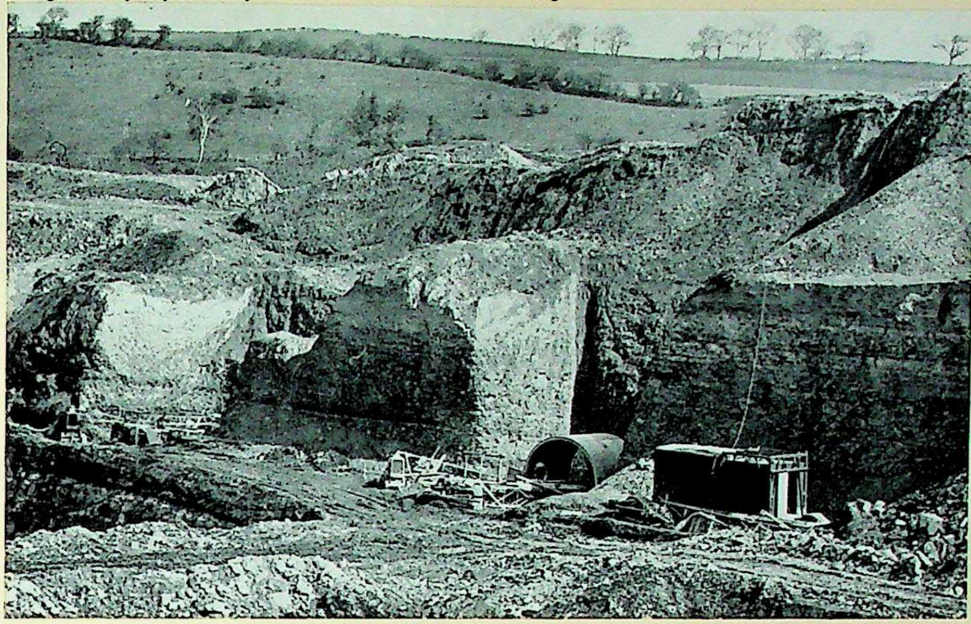

FIGURE 5 – *Photograph showing the boring of a horizontal hole to connect with vertical holes drilled from the high ground at the right of the photograph.*

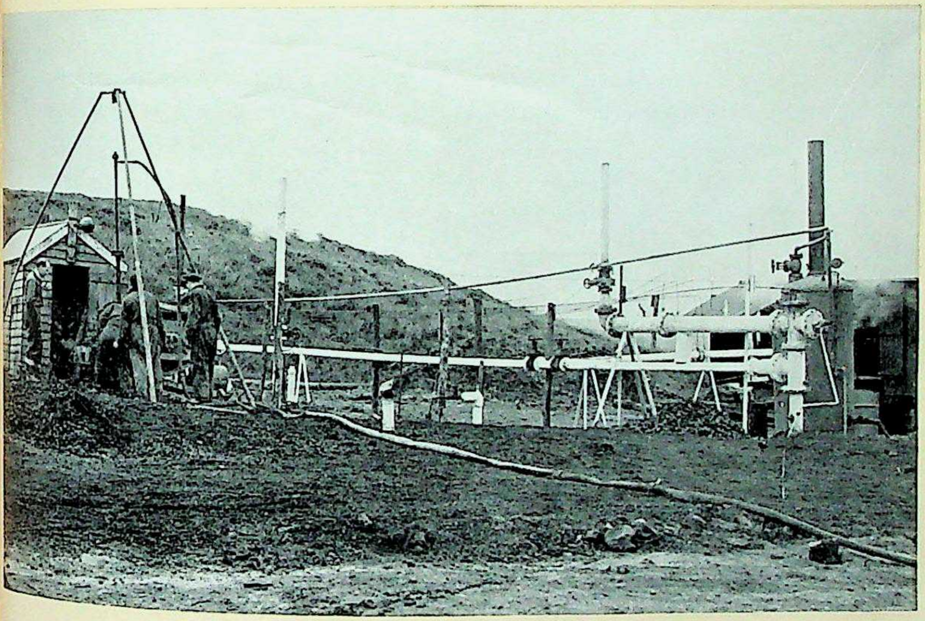

FIGURE 6 – *Apparatus for the first prolonged trial of underground gasification, which began in July 1950. The compressed-air supply comes into the horizontal pipe at the valve gear near the centre of the photograph. It can then be taken to the left or to the right at will, so permitting the flow through the underground system to be reversed when desired. The thicker, shorter, horizontal pipe is an addition required to connect a meter for measuring the flow. The vertical holes are 50 ft apart.*

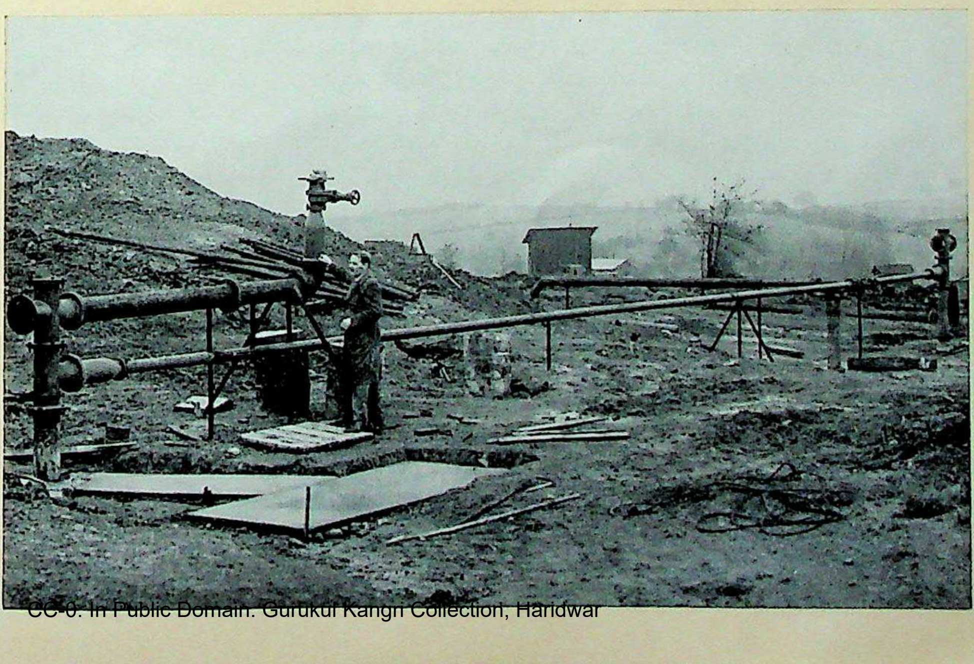

FIGURE 7 – *Photograph showing a second system made by connecting horizontal and vertical drillings; the vertical holes are 75 ft apart.*

(*Figures 5–7 Crown Copyright reserved*).

by underground gasification, how much better a proposition should be the underground gasification of good coal in good seams. Consideration of this view can safely be postponed, however: at the present time more coal is wanted than can be mined, and there is a very great deal to be done in underground gasification before any serious suggestion can be made that it might, in certain circumstances, replace conventional methods of coal mining. In Britain, at any rate, underground gasification must begin on coal which would otherwise have no value. When the technical problems are overcome, it will be time to think about whether underground gasification provides in any circumstances of power production a better solution than conventional mining.

There is more than one way in which to classify the possible methods of underground gasification, but there is a convenient division into methods which require that men shall go underground to prepare the system and methods in which all the work is done on the surface. Most of the underground gasification done in Russia, and the experiments now in progress in the United States, Belgium, French Morocco, and Italy, are based upon the former method. There is some evidence, however, that the so-called percolation method, in which the whole operation is conducted from the surface, has been tried in Russia, and the assessments recently made in Britain indicate that, if this method can be successfully developed, it offers better economic prospects than the alternatives demanding direct underground workings. British workers have, therefore, started with the successful development of the percolation method as their first aim.

Given the objective of underground gasification based on surface working, the problem in the field separates into two parts. On the one hand, we need to find a good, generally applicable method of connecting the bottoms of vertical bore-holes. On the other hand, we need to study the processes of gasification and the quality of the product. On the site chosen for the initial British work, which is at Newman Spinney, near Chesterfield, the gasification part of the problem was started first. A system of the kind illustrated in figure 1 was adopted, the method used for establishing underground gasification connection being the horizontal bore-hole method illustrated in figure 2. Newman Spinney being an opencast mining site, the vertical drillings were made from the high level, and the horizontal drilling was made inwards from the more or less vertical wall left by the opencast mining operation. The problems of location involved in ensuring the conjunction of the vertical and horizontal drillings are in themselves of great interest, and will be described elsewhere in a paper which is now in preparation.

The first short runs with this system were made in April 1950, with limited success. A great deal of experience was gained then, however, so that on 13th July a prolonged run was begun with some confidence, and it was successfully continued for more than four months. The seam which is being gasified is of a most inferior kind, and would never have been mined. It is wet, and is divided into layers of shale and layers consisting half of coal and half of dirt. The calorific value of the gas produced has varied very considerably. It has at times been as low as 10 B.Th.U./cu ft, yet has attained unexpected, and to some extent unexplained, peaks, the highest of which was 497 B.Th.U./cu ft. The average calorific value for the first ten weeks was about 80 B.Th.U./cu ft, but it later dropped, so that the average over the whole period at the time of writing is about 50 B.Th.U./cu ft. The composition of the gas varies quite considerably, but specimen analyses are as follows:

1950	CO_2	O_2	CO	CH_4	C_nH_m	H_2	N_2	Cal. Val. (B.Th.U./cu ft)
	per cent. by volume							
23rd August	13·4	0·1	11·2	1·3	0·2	10·8	63·0	87
11th September	15·5	—	4·9	1·0	—	7·9	70·7	51
21st October	10·2	9·5	1·0	0·9	—	1·1	77·3	16

Although the method of horizontal drilling used to establish connection between vertical bore-holes can be conveniently adopted in certain circumstances, it is not the generally applicable method for which we are seeking in the second part of our work. The possibility of some form of mechanical mole which, starting down in a vertical direction, can drill more or less horizontally, has naturally not been overlooked. The varying success on these lines in drilling for oil has been studied, but the difficulties of this solution are such that it has, for the time being, been relinquished in favour of the investigation of techniques dependent on the application of high pressures. The idea is that high pressure, whether pneumatic, hydraulic, or explosive, will open up the natural fissures in the coal, or lift the over-burden from it, and thereby create a passage for gas between vertical boreholes. The first experiments have been made with pneumatic pressure, and it has been found that the application of a pressure equal to that imposed on the coal seam by the overburden does, in effect, open up natural channels. Twenty per cent. of the air pumped down one vertical hole at a pressure of 100 lb/sq inch came up another vertical hole 33 ft away. Experiments of this character are still in progress. Considerably longer channels have been established, and ignition under pressure has recently been achieved.

The products of underground gasification in Britain are unlikely to have mean calorific values more than about one-fifth of that of the normal town's gas. For most of the purposes for which town's gas is used, therefore, they are not likely to supersede it. If gas from underground gasification has a future it will be as a means of heating, or as a power gas—that is, as a fuel for engines generating power. The second is the more likely application. One method would be to use it for boilers generating steam for steam-engines. Another method would be to use the gas as a fuel for gas turbines generating electrical energy. The fact that the gas is of a low calorific value is not a disadvantage, as the gas turbine can conveniently be worked on dilute fuels. The experiment at Newman Spinney is on a very modest scale—the vertical boreholes are 4 in in diameter and only about $1\frac{1}{2}$ tons of coal a day is being consumed—yet a small gas-turbine using the gas produced could generate about 50 kilowatts of electrical power.

This is not being done, and there is no plan at present to couple up a gas-turbine to an underground gasification system. The time to do this will be when the essential underground gasification problems are more fully understood. If there are any specific gas-turbine problems arising from underground gasification, they still remain to be discovered.

The gas-turbine will demand a reasonably steady supply of gas of reasonably consistent quality. The fluctuations experienced in the first Newman Spinney system would be inconvenient. When one imagines several such systems, however, forming a single supply to a gas-turbine power plant, the possibility of levelling out the fluctuations is obvious.

The best way of co-ordinating a set of systems of the kind shown in figure 1 has not yet been decided. A number of different geometrical arrangements are possible. In general terms, however, what we eventually hope to do, if our initial programme of research is sufficiently successful, is to exploit an area of hitherto useless coal by means of scores of small vertical shafts, with the products of combustion piped to gas-turbine engines generating electricity and passing it into the electricity network.

It is perhaps wise to conclude by emphasizing two points. One is that the realization of the vision just described may, even with complete technical success, be severely restricted in Britain. There are certainly many millions of tons of coal there which will never be mined by ordinary methods, but the density of our population is so high that the number of areas suitable for underground gasification may prove to be limited. There may be wider opportunities in other parts of the world.

The second point is that we are in the early stages of a relatively small-scale experimental programme, and must not develop too great an optimism on the basis of its undoubted initial success.

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Vegetable acids in higher plants

MEIRION THOMAS

The study of vegetable acids is an old one. In the eighteenth century Scheele isolated oxalic, malic, citric, and tartaric acids. In India in the early nineteenth century Benjamin Heyne made the first observation of the diurnal variation in acid content now known to occur in the green parts of certain succulent types of plant. A few years earlier, without knowing anything about the acidity of succulent plants, de Saussure reported facts about the gaseous exchanges of a cactus which were not thought significant and which have only recently been interpreted in terms of carbon dioxide fixation as a metabolic event in acid synthesis.

When a plant organ has a sour taste, one or more di- or tricarboxylic acids will have accumulated in it to reach a not inconsiderable concentration. The titratable acidity of the sap will be high, and the *p*H relatively low, owing to the presence of free acids and their acid salts. In table I are recorded in normalities, and as *p*H values, the acidities of the saps expressed from some of the organs seen in figure 3.

TABLE I

Titratable acidities stated in normalities and as *p*H values, determined potentiometrically and by indicators (see figure 1), of saps expressed from some of the organs photographed in figure 3 and from certain other organs. (Experiments by Mr J. M. A. Brown at King's College, Newcastle upon Tyne, September 1950.)

Organ from which sap was expressed	*Normality of sap*	*p*H *of sap*
Lemon fruit	0·95	2·4
Red-black fruits of blackberry	0·23	2·7
Rhubarb petioles	0·22	3·2
Unripe grapes	0·21	3·0
Oxalis leaves	0·16	2·3
Green cooking apple	0·13	3·2
Begonia rex leaves	0·11	2·2
Begonia tuberosa, var. leaves	0·10	2·2
Ripe tomato fruit	0·063	4·4
Ripe Worcester Pearmain apple	0·045	3·9
Celery petioles	0·025	5·2
Root of white beet	0·025	5·8

TITRATABLE ACIDITY

The accumulation of titratable acids in the juice of ripe lemons is remarkably high—much greater than in any of the other organs examined. In some plant organs the accumulation may be even lower than in celery petioles and the root of white beet; it is, however, not improbable that titratable acidity would be measurable in the saps of all plant organs at all stages in their development and under all environmental conditions.

For a given plant, heredity determines the nodal value about which the titratable acidity of an expressed sap will vary. The sourest apple will never be as acid as the least sour lemon, and, among apples, cooking varieties, even when ripe, will be more acid than a dessert apple such as Worcester Pearmain in late September.

Apart from inherited individual differences in a given variety of plant, soil and climate will exert an influence. Nurtured under unfavourable conditions, the choicest grape may remain disagreeably tart by retaining its accumulated acids.

The results of quantitative experiments give exact expression to the fact vouched for by the sense of taste that, in aging, a plant organ often becomes less sour. For example, in one experiment performed in the United States, it was found that the acidity of the juice of Valencia oranges decreased from 0·39N to 0·13N as the fruit ripened.

THE INDIVIDUAL ACIDS

In the legend to figure 3, some facts are recorded concerning the distribution of nearly all the individual di- and tricarboxylic acids listed below.

Oxalic acid

$HOOC.COOH$

Succinic acid

$HOOC.CH_2.CH_2.COOH$

Fumaric acid

$HOOC.CH = CH.COOH$

Malic acid

$HOOC.CH_2.CHOH.COOH$

Oxalacetic acid

$HOOC.CH_2.CO.COOH$

Tartaric acid

$HOOC.CHOH.CHOH.COOH$

α-Ketoglutaric acid
$HOOC.CH_2.CH_2.CO.COOH$
Oxalsuccinic acid
$HOOC.CH_2.CH(COOH).CO.COOH$
Citric acid
$HOOC.CH_2.C(OH)(COOH).CH_2.COOH$
iso-Citric acid
$HOOC.CH_2.CH(COOH).CHOH.COOH$
cis-Aconitic acid
$HOOC.CH_2.C(COOH) = CH.COOH$
Tricarballylic acid
$HOOC.CH_2.CH(COOH).CH_2.COOH$

Most of these facts have been known for a long time. Scheele, in the eighteenth century, succeeded in separating oxalic, malic, citric, and tartaric acids from plants or plant products, and knowledge concerning the distribution of these and the other acids mentioned in the legend (except *iso*-citric acid) increased sporadically during the nineteenth century and the early years of the present century.

Iso-citric acid was synthesized by Fittig in 1889, but its occurrence in nature was not demonstrated until 1927, when Nelson extracted it from blackberry fruits and prepared its hydrazide. Nelson found that five-sixths of the acidity of the fruits was attributable to *iso*-citric acid. He also reported the presence of this acid in the leaves. It is now believed that *iso*-citric acid plays an essential part in the aerobic metabolism of all living cells.

All plant saps may contain a mixture of di- and tricarboxylic acids, but one or more may predominate. Thus oranges and apples contain citric and malic acids in easily recognizable amounts, and other acids in much smaller amounts. In oranges, citric acid reaches a much higher concentration than malic acid: in apples malic acid predominates. These are the two acids which have been most frequently found in considerable accumulation in edible organs. Accumulations of tartaric acid appear to be rare. We have insufficient data about *iso*-citric acid to venture a general statement. It accumulates in high concentrations in *Bryophyllum* leaves (see below). Free oxalic acid has a wide distribution, and in certain organs (e.g. rhubarb leaves) reaches concentrations high enough to render them poisonous.

TOTAL ACIDITY

The anions of di- and tricarboxylic acids accumulate not only in free acids and acid salts, but also in normal salts, some of which (e.g. potassium and ammonium salts) are soluble, and one at least (*viz.* calcium oxalate, of wide distribution) is insoluble. In addition, vegetable acids combine with nitrogenous bases, such as alkaloids. Total acidity is a measure of the acid anion concentration, and is clearly the best index of the intensity of acid metabolism. In rhubarb petioles, total acidity may be double the value of titratable acidity. In these petioles, and indeed in plant organs in general, the synthesis and accumulation of the acid anions occur gradually as the organs grow. Simultaneously, nitrate, sulphate, and phosphate anions absorbed from the soil are used in anabolism. The residual cations combine with the carboxylic anions. One function of acid synthesis, therefore, may be the control of the hydrogen ion concentration of cell sap.

HYDROGEN ION CONCENTRATION

All expressed plant saps are acid to litmus. In general their *p*H values are less than 5·5, but relatively high values have been reported for saps from certain leaves, e.g. fig (6·8), spinach (6·5). Values as low as 1·5 have been found for *Begonia* and *Oxalis*. The range of values in table I is from 2·2 to 5·8 (see also figure 1). Like those for titratable acidity, these values are determined in part by inheritance, and in part by the age of an organ and the environmental conditions prevailing during development. Thus the *p*H of lemon juice is probably always less than 3 and greater than 1, and that of beet juice greater than 5 and less than 7. Within these limits there may be much variation. In one experiment (see p. 160) it was found that, during the ripening of Valencia oranges, the *p*H of the juice increased from 2·9 to 3·8, owing to the consumption of titratable citric acid.

It is noteworthy that the normality and the hydrogen ion concentration of saps are not always directly related. This is owing in part to the different degrees of buffering of the saps, and in part to differences in the dissociation constants of the accumulating acids (see table II).

TABLE II

Dissociation constants at 25° C

Oxalic acid ..	.. $6{\cdot}5 \times 10^{-2}$
Malic acid ..	.. 4×10^{-4}
Tartaric acid ..	.. $9{\cdot}7 \times 10^{-4}$
Citric acid ..	.. $8{\cdot}7 \times 10^{-4}$

The normality of lemon juice may be nearly ten times greater than that of sap from *Oxalis* or *Begonia* leaves; but the *p*H of these saps is usually less than that of lemon juice, because oxalic acid, with a relatively high dissociation constant, accumulates predominantly in them, whereas citric acid, a weak acid, is mainly responsible for the titratable acidity of the lemon juice.

ACID METABOLISM

Whether or not, over a period, an acid will accumulate or disappear, will be determined by the relative rates of its metabolic production and consumption. In many plant organs the rate of production for one or more acids must, on balance over the growing season, exceed the rate of consumption. However, in ripening fruits consumption is usually more rapid than production.

Certain plants are specialized in that they show diurnal variation in acidity. Their behaviour will be considered below under the heading 'Crassulacean acid metabolism'. There is no reason to believe that the biochemical mechanisms governing the production and consumption of acids in these plants are essentially different from those which operate in other plants.

Indeed, it is not improbable that the enzymic systems at work, and the sequence of changes, in the higher plants are very similar to those which have, in recent years, been elucidated by the brilliant investigations of Krebs, Martius and Knoop, Wood and Werkman, Ochoa, and others, on animal tissues and bacteria. It has been established that, in their aerobic metabolism, animal and bacterial cells can produce and consume di- and tricarboxylic acids. In general, consumption is relatively the more rapid process, and the acid molecules have short lives. For this reason the phenomenon of the metabolism of these acids in animal and bacterial cells was overlooked until about fifteen years ago. Only in green plants and certain mould fungi had considerable accumulations been found, which is why these acids were called vegetable acids. We now have more detailed biochemical information about the metabolism of vegetable acids from studies performed on animal tissues than from those carried out on plants. Some of this information is summarized below under the heading tricarboxylic acid cycle.

CRASSULACEAN ACID METABOLISM

The peculiarities of this form of metabolism are stated in the legend to figure 4. The phenomenon of diurnal variation in acidity was first decribed in 1813 by Benjamin Heyne in a letter to A. B. Lambert, vice-president of the Linnean Society. Heyne had tasted *Bryophyllum* leaves in India, and wrote: 'The leaves of the *Cotyledon calycina*, a plant called by Mr Salisbury *Bryophyllum calycinum*, which on the whole have a herbaceous taste, are in the morning as acid as sorrel, if not more so; as the day advances, they lose their acidity, and are tasteless about noon and become bitterish towards evening.'

The results recorded in table III and figure 2 give the changes in titratable acidity and *p*H in an experiment on leaves taken from *Bryophyllum* plants similar to the one illustrated in figure 4. The temperature was reduced during the dark period, because it is known that low temperatures may favour dark acidification.

TABLE III

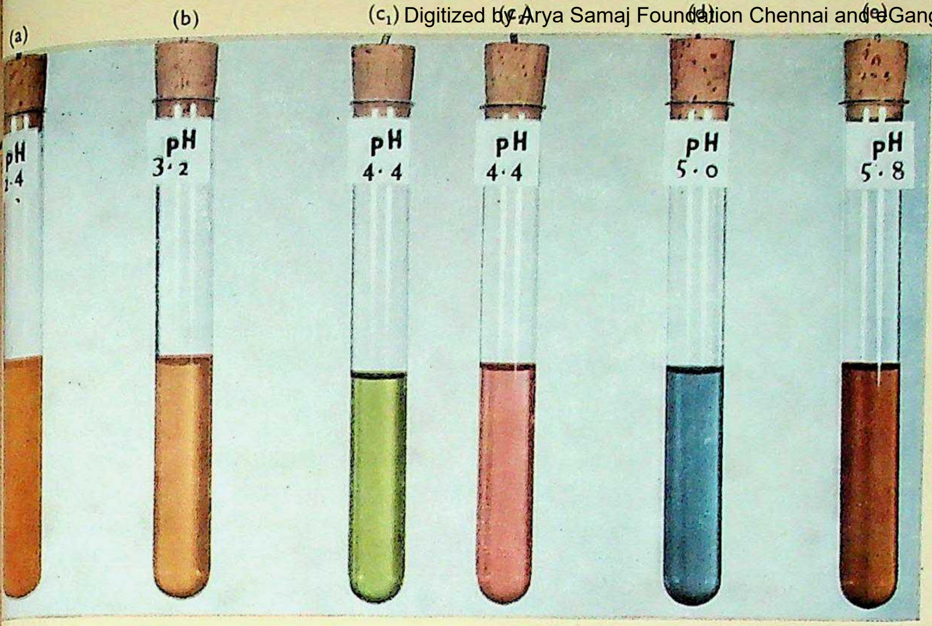
Diurnal variation in acidity of leaves of Bryophyllum calycinum. (*J. M. A. B., Sept.* 1950)

Conditions before analysis	*Normality of sap*	*p*H *of sap (see figure* 2)
(*a*) 26 hours illumination. Room temperature	0·03	5·05
(*b*) 26 hours illumination and 24 hours dark. 10° C	0·08	4·56
(*c*) 26 hours illumination, 24 hours dark, and 5 hours illumination. Room temperature	0·02	5·40

*p*H values were previously determined potentiometrically.

Numerous quantitative investigations have been made of dark acidification and light deacidification, culminating in more recent times in those of Bennet-Clark in Britain, Wolf at Leipzig, and Vickery and Pucher and their colleagues at Connecticut. Vickery and his colleagues showed that the principal acids in *Bryophyllum* leaves are *iso*-citric, malic, and citric. *Iso*-citric acid may reach a high concentration. Indeed, *Bryophyllum* is now sometimes grown to serve as a source of this acid for chemical and biochemical experiments. However, diurnal fluctuation in *iso*-citric acid is slight. Acidification is mainly due to the accumulation of malic acid, and deacidification to the depletion of the store. In the dark, this acid is produced more rapidly than it is consumed; in the light, consumption is the faster process. From Newcastle has come a suggested explanation for these changes in rate, and also some experimental evidence in support of it.

The investigators named in the last paragraph have established beyond reasonable doubt that malic acid is derived from carbohydrate. After



URE 1 – *Colours given by appropriate indicators with certain expressed saps (see table I) ose* pH *values had been determined potentiometrically.* (a) *Lemon juice and thymol-blue;* (b) *ubarb juice and brom-phenol-blue;* (c_1) *Tomato juice and brom-cresol-green;* (c_2) *Tomato juice methyl-red;* (d) *Celery juice and brom-cresol-green;* (e) *Beet juice and brom-cresol-purple.*

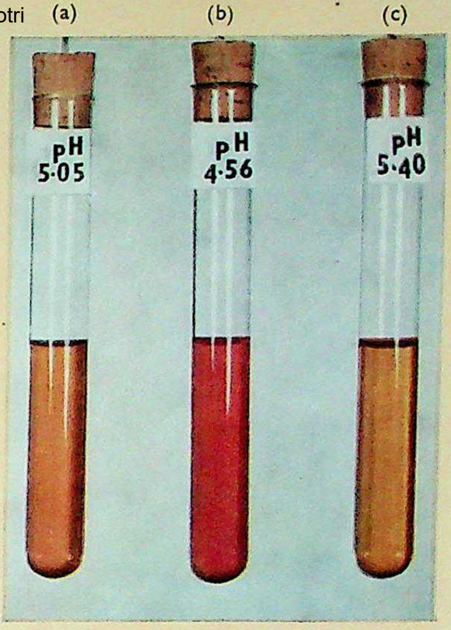
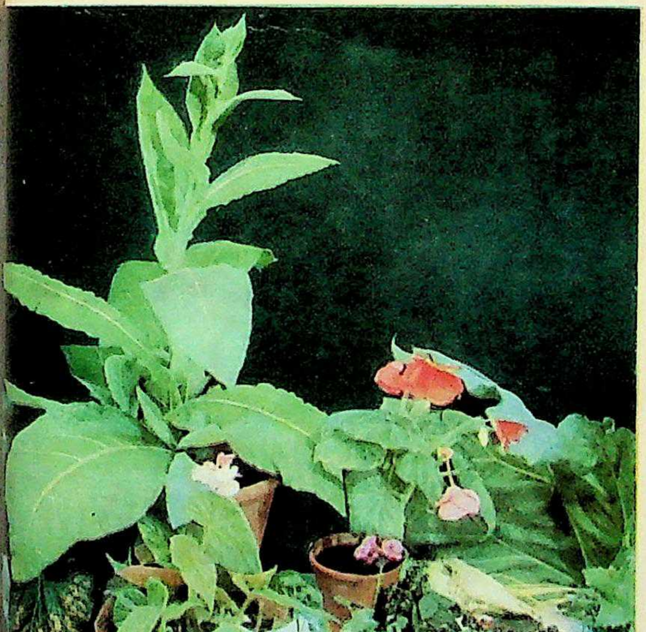


FIGURE 2 – *Colours given when methyl-red was added to saps expressed from* Bryophyllum *leaves treated respectively as described in table III* (a), (b) *and* (c).



RE 3 – *The plants shown in this collection have the power of ulating one or more vegetable acids, but not the property of diurnal ion in acidity. The specimens include apple, rhubarb petiole, -leaves, and ivy-leaved* Pelargonium (*malic acid*); *lemon* (*citric fruit and leaves of blackberry* (iso-*citric acid*); *fruit and leaves pe* (*tartaric acid*); *leaves of* Begonia, Oxalis *and rhubarb* (*oxalic unripe beet* (*aconitic and tricarballylic acids*).

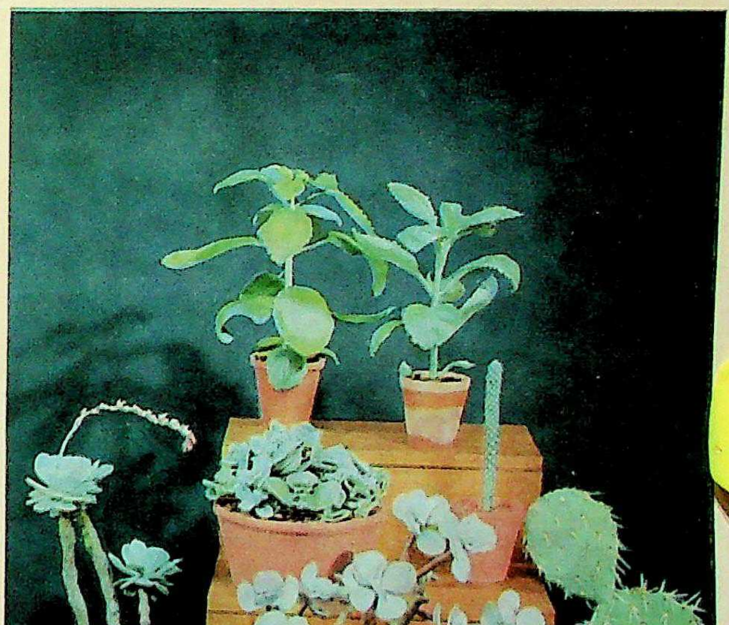


FIGURE 4 – *The plants shown in this collection possess the peculiarity of accumulating acids in the dark at certain seasons and consuming them again during the day. The plants are* (*from left to right*) *as follows:* (*Top shelf*) Bryophyllum calycinum, Kalanchoe *sp.*; (*Second shelf*) Crassula lactea, Opuntia cylindrica; (*Third shelf*) Echeveria [illegible]; (*Bottom shelf*) Sedum praealtum, Crassula arborescens, Sempervivum *sp.*

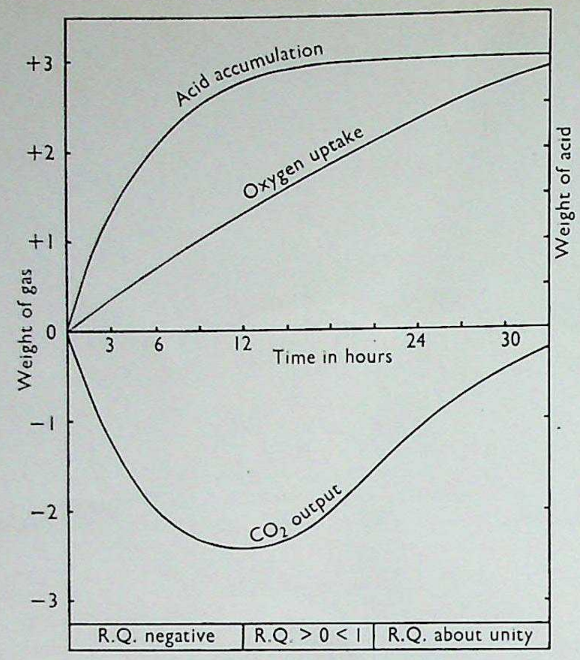


FIGURE 5 – *The curves give a generalized representation of the results of Newcastle experiments performed by Beevers and Ranson. Carbon dioxide and oxygen are simultaneously absorbed from a gas mixture containing oxygen and 5 per cent. carbon dioxide during intensive dark acidification of plants showing Crassulacean acid metabolism. The values of respiratory quotients are negative during this phase. Later, when the rate of acidification declines, these values become positive, gradually rising from zero to unity. Normal respiratory gaseous exchange then occurs according to the equation:*

$$C_6H_{12}O_6 + 6O_2 = 6\,CO_2 + 6\,H_2O.$$

When values of the respiratory quotients lie between zero and unity, some of the respiratory carbon dioxide is consumed in the synthesis of malic acid, and therefore fails to escape. A possible overall equation for this synthesis is

$$C_6H_{12}O_6 + 2CO_2 = 2\,C_4H_6O_5.$$

When these values are negative, carbon dioxide absorbed by the leaves, in addition to respiratory carbon dioxide, is consumed.

glycolysis, the Wood and Werkman reaction (see figure 6) could operate on pyruvic acid or its phospho-derivative, leading either to the synthesis of oxalacetic acid, and the reduction of this compound to yield malic acid by the successive action of the enzymes oxalacetic carboxylase and malic dehydrogenase, or to the direct synthesis of malic acid by what is called the malic enzyme.

The Wood and Werkman reaction involves the fixation of carbon dioxide. The first proof that carbon dioxide is an essential metabolite in the biosynthesis of dicarboxylic acids was obtained in experiments on bacteria and pigeon's liver. A consideration of certain recorded facts relating to the gaseous exchanges of plants showing Crassulacean acid metabolism strongly suggested that the fixation of respiratory carbon dioxide accompanied acid accumulation in the dark. Some 150 years ago, Th. de Saussure, in his *Recherches Chimiques sur la Végétation*, showed that cactus shoots, placed after sunset in a closed space, absorb oxygen without giving off carbon dioxide; thus the respiratory quotient is zero. Numerous experiments performed at Newcastle in 1946 and subsequently, and the results obtained in Bonner's laboratory in California, have provided evidence of this fixation.

When leaves which do not show Crassulacean acid metabolism are placed in the dark in a gas mixture containing air enriched with carbon dioxide, oxygen is absorbed, carbon dioxide is liberated and the value of the respiratory quotient is usually about unity. In striking contrast: when, at the outset of a dark period, acidification is most intense in leaves which accumulate malic acid in the dark, carbon dioxide and oxygen may be simultaneously absorbed (see figure 5). The CO_2 output may be regarded as negative, which implies a negative value for the respiratory quotient. Actually this singular fact was observed nearly 150 years ago by Th. de Saussure, who showed that in the dark a cactus in air enriched with carbon dioxide absorbed oxygen and carbon dioxide simultaneously. The few later workers who took notice of this effect lightly dismissed it as an effect of solubility and of no physiological significance. Indeed, the 'de Saussure effect' (as the present writer and Wolf have independently suggested that the absorption of carbon dioxide during dark acidification should be called) could not have been interpreted until the discovery of the Wood and Werkman reaction.

Light deacidification in Crassulacean acid metabolism is attributed to the virtual stopping of the carbon dioxide supply to centres of acid synthesis in green leaves. In the light this gas is preferentially consumed by the chloroplasts in photosynthesis, and little or none is available for the Wood and Werkman reaction. Acid consumption continues, and as the stores are not replenished the titratable acidity of sap declines and the *p*H value rises.

THE TRICARBOXYLIC ACID CYCLE

Sound evidence has been obtained for the view that in animal tissues the aerobic katabolism of carbohydrate predominantly occurs in a manner closely similar to that outlined in figure 6.

Phosphorylative glycolysis yields pyruvic acid

$(CH_3.CO.COOH)$.

This compound or its phospho-derivative may condense directly with oxalacetic acid already present in the cell to form *cis*-aconitic acid. Alternatively, the pyruvic acid may first be converted into acetyl phosphate before the condensation takes place. The condensation is an oxidative decarboxylation. A series of hydrations, dehydrogenations, and decarboxylations then take place, each under enzymic control. The smooth working of the dehydrogenases depends upon a continuous oxygen uptake. *Cis*-aconitic acid is oxidatively decomposed with liberation of carbon dioxide and water, and with the regeneration of oxalacetic acid, which can once again take its catalytic part in the cycle of changes indicated by the heavy lines in figure 6.

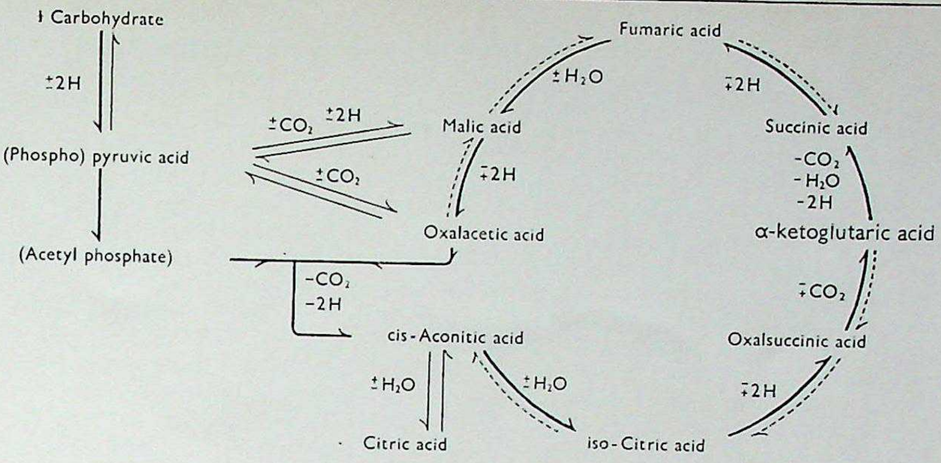


FIGURE 6 – *A representation of the tricarboxylic acid cycle, indicating possible methods by which vegetable acids are produced and consumed. All the individual reactions, except the oxidative decarboxylations leading to the production of* cis-*aconitic and succinic acids, have been shown to be reversible.*

It is noteworthy that of the acids believed to be produced in this cycle, *cis*-aconitic, citric, *iso*-citric, succinic, fumaric, and malic acids may accumulate in plant tissues (see p. 160). It is a useful working hypothesis, therefore, that they may be produced in plants by mechanisms similar to those which have been studied in animal tissues, and in the same sequence. The body of evidence supporting this view is not yet very substantial. The accumulation in a plant tissue of a certain acid (e.g. citric acid in citrus fruits, *iso*-citric in the blackberry fruits, fumaric acid in fumitory) would mean that the conditions in the cell, determined by the inheritance of the plant, the stage of development, and environmental conditions, favour the enzymic production rather than the enzymic consumption of the acid.

It is not yet known whether any connection exists between the formation of oxalic, tartaric, and tricarballylic acids and the reactions occurring in the tricarboxylic acid cycle. However, there is strong evidence that some of the substances produced in the cycle of changes are intermediate compounds in the formation of certain amino-acids and other important metabolites. Research during the last fifteen years has firmly placed the vegetable acids in a central position in theories concerning the chemical economy of all living cells.

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Book reviews

PARTICLE ACCELERATORS

Machines Atomiques, *by Maurice E. Nahmias. Pp.* 310, *with numerous half-tones and line diagrams. Editions de la Revue d'Optique Théorique et Instrumentale, Paris.* 1950. *Bound* 1,480 *francs; paper cover* 1,200 *francs net.*

This book is a much-expanded version of an earlier work (*Le Cyclotron*, 1945). It describes all the familiar particle accelerators and some unfamiliar ones, such as a plant in Switzerland where an attempt was made to build a 10 MV supply by tapping the electric charge of thunder clouds. Concise and effective descriptions are given for each system, with derivations of the necessary equations of motion of the accelerated particles. In each case appropriate numerical examples are given, applicable to existing machines, which help a great deal in appreciating the significance of the formulae produced. The principles and properties of atomic piles are briefly but adequately described.

Interspersed among the descriptions of machines are discussions of the types of nuclear reactions which they make possible. This helps to make the book interesting and easy to read. There is no doubt that it will prove most useful to any physicist entering a laboratory concerned with the production of high-energy particles.

Some of the figures quoted should not be relied on; for example, the Birmingham cyclotron is 155 cm, not 100 cm as stated, and the voltage and current quoted for the Birmingham proton synchrotron are both ten times too low. It is a great pity that the book has no index. J. H. FREMLIN

ORGANIC CHEMISTRY

Principles of Ionic Organic Reactions, *by Elliot R. Alexander. Pp.* 318. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1950. 44*s. net.*

In this book the author strives to find common principles for a large number of reactions resulting in the elimination or addition of groups. Beginning with simple rearrangements such as the formation of carbonium ions, the discussion embraces more complex processes such as the Grignard and Wurtz reactions, Claisen condensations. diazonium coupling, and double-bond migration. These principles are based on the electronic structure of the bonds, their permanent and induced polarization, resonance, and other effects, and they are discussed in qualitative and non-mathematical language. As the book is intended for organic chemists, the exclusion of mathematics is an advantage. However, the systematic omission of fundamental physico-chemical data, such as free energies, reaction rates, and temperatures, will be regretted by many modern organic chemists. A knowledge of these data would greatly facilitate the understanding of reactions, especially as any discontinuities in their trend are usually indicative of a change of reaction mechanism.

The book as a whole represents an extensive survey of ionic organic reactions and their significant literature up to 1949. It is well written and easy to follow, and the author must be congratulated on having produced a book which constitutes a valuable addition to the library of every organic chemist. E. GLUECKAUF

A BOOK OF TABLES

The Scientist's Ready Reckoner, *by W. Roman. Pp.* 142. *Dr W. Junk, The Hague, Holland.* 1950. *fl.* 6.50 *net.*

This is a somewhat unusual book of tables. It is especially fitted for the use of chemists and physicists working in analytical laboratories, and it may prove useful to research workers in technical institutions. The tables published are: (1) a list of international atomic weights and their logarithms; (2) and (3) tables of atomic weights, followed by a fairly comprehensive list of compounds and of the weights of frequently occurring radicals; (4) and (5) gravimetric and volumetric factors and their logarithms; (6) specific gravities of liquids and solutions; (7) a table for the conversion of temperatures of the Kelvin scale into Fahrenheit and Centigrade scales, and conversely; (8) and (9) tables of four-figure and five-figure logarithms.

The book is beautifully produced, but there are one or two minor points which it may be well to consider here.

There is a tendency nowadays to cut down the use of rules in the setting-out of tables, and to rely more on the grouping of the rows and columns by the use of spaces. The inconvenience caused by insufficient breaking up of the blocks of figures is especially evident in table (7) for temperature conversion. Surely the use of the low point to indicate decimal fractions is unusual; a high point is the usual practice, and a low point indicates multiplication.

The editor proposes to publish other parts; Part II is scheduled to contain 'a comprehensive list of conversion factors for metric, international, and national weights and measures, together with their logarithms.'

Natural logarithms—that is, logarithms to the base *e*—should never be called Napierian logarithms. Napier's logarithms, though related to natural logarithms, were very different.

We trust that Part I will have a wide circle of users. It is, as we have said, remarkably well produced, is easy to handle, and is issued at a reasonable price. ALLAN FERGUSON

TEMPERATURE AND HUMAN LIFE

Temperature and Human Life, *by C. E. A. Winslow and L. P. Herrington. Pp.* 272. *Princeton University Press, U.S.A.; Oxford University Press, London.* 1949. 28*s. net.*

The study of the reactions of the human body to the conditions of its environment may be said to have been initiated by Sanctorius in 1614, in *Ars de Medica Statica*, but advance was slow during the following three centuries. The early development of the profession of the heating and ventilating engineer was based on the erroneous idea that the purpose of ventilation was to remove or dilute the organic poisons formed in the breath, and it was in a sense an accident that ventilation removed the excess heat from the body.

The book under review gives a coherent and interesting account of the work done in the United States, during the present century, by the American Society of Heating and Ventilating Engineers (established some thirty years ago), and later in the authors' own laboratory, the John B. Pierce Laboratory of Hygiene (established in 1933). The work done in the latter laboratory, under the directorship of Dr Winslow, forms the main basis of this book, but the work done elsewhere is also reviewed, giving a clear picture of our present knowledge of experimental hygiene. The reactions of the human body to a wide range of air temperature, humidity, air speed, radiation from surrounding solid bodies, and degree of exertion, are described with outstanding clarity.

The history of the development of our present knowledge is presented in an interesting manner, and we find here some little-known facts concerning early attempts to understand the basic facts of environmental hygiene. For example, according to Heidel, a Greek, Erasistratus (in the third century B.C.), experimented with a respiration calorimeter, finding the loss in weight of fowls placed in a jar, due to what we now call insensible perspiration.

The lay reader will perhaps be surprised to find that while the metabolic rate is proportional to the area of skin in any particular mammal, it is subject to only very slight variation in different mammals except the very largest, such as the horse or the elephant, when observed in similar conditions.

For thermal balance of the human body, the rate of production of heat within the body must be balanced by the combined effects of the loss of heat by evaporation, and the gain or loss of heat by convection and by radiation. The third chapter of this book discusses the items in the thermal budget, and describes the reactions of the body to meet varying conditions in the environment; it is very fully illustrated by tables and diagrams.

Four further chapters deal with the protective influence of clothing, the problems of air conditioning (which are physical and not chemical, cutaneous and not respiratory), the methods of air conditioning, and the effects of climate and weather on health.

Many of the problems discussed in this book became urgent during the war, notably those concerned with the design of clothing suitable for men exposed to extreme conditions of temperature and of physical effort. These problems are discussed in some detail, in a manner which gives a clear insight into the methods of applying the results of the experiments made in the laboratory to both indoor and outdoor life in varying conditions.

The book ends with a well-selected bibliography, containing 151 entries, covering all aspects of the material discussed in the seven chapters.

The lucid style of writing, and the careful selection and discussion of the matter to be included, make this book a valuable contribution to the literature of experimental hygiene. It fills a notable gap in this literature, a gap which has in the past made it almost impossible for anyone but an expert worker to acquire a reasonable knowledge of what was definitely known, and of what yet remained to be found. Even with a meagre knowledge of physiology, the reader of this book will be able to grasp most of its arguments and conclusions. At the same time there are parts of the book which will make a special appeal to the expert. Thus in Chapter VII will be found some facts which will appeal to the expert epidemiologist, in the discussion of climate, weather, and health.

D. BRUNT

KINETIC THEORY OF LIQUIDS

A General Kinetic Theory of Liquids, *by M. Born and H. S. Green. Pp.* 98. *Cambridge University Press, London.* 1949. 10*s.* 6*d. net.*

This is not a book for the layman. It can, indeed, be appreciated by the expert only after concentrated study. It is a reprint of six papers from the *Proceedings of the Royal Society*. The first four are devoted to the general kinetic theory of liquids, and their main achievement is the development of a mathematical technique to deal with the special features of a liquid—that the molecules do not keep the same set of neighbours as in a solid, and yet do not move nearly independently of one another as in a gas. The theory leads to a distinction between different legitimate uses of the words 'pressure' and 'temperature' in dealing with a moving liquid. Such distinctions are elaborated in the fifth paper, which deals with the kinetic approach to thermodynamics. The methods are applied in the last paper to the properties of liquid helium, in an attempt to understand its remarkable properties. The book is not intended as a comprehensive treatise on liquids, but rather as a preliminary introduction to the potentialities of a new approach.

M. H. L. PRYCE

JAN INGENHOUSZ

Jan Ingenhousz, Plant Physiologist, with a History of the Discovery of Photosynthesis, *by Howard S. Reed. Pp.* 105, *with* 8 *plates. Chronica Botanica Company, Waltham, Mass.; Wm. Dawson and Sons, London.* 1949. $3 *net.*

Dr Reed has earned the gratitude of botanists by devoting his retirement to studies in botanical history. His first book was, perhaps, too ambitious to satisfy most of his readers. The present book is a reprint of Ingenhousz's *Experiments on Vegetables*, with editorial comments by Dr Reed, and it will be welcome in every botanical library. Ingenhousz published this book in English in 1779. It is a landmark in the history of plant physiology, for it contains the evidence that plants 'correct foul air unfit for respiration' only in light, and that this activity is centred in the leaves.

Ingenhousz's essay is refreshing to read for three reasons. In the first place, it is written with an unaffected charm which makes one realize that in order to be lucid and unambiguous it is not really necessary to adopt the gawky style affected by many modern research workers in their papers. In the second place, it displays a courtesy toward other workers in the same field (especially to Priestley) which is an example of the highest traditions in science. In the third place, it serves to remind physiologists that the teleological approach, lamentable as it may be to the philosophers of biology, is not incapable of leading to scientific results of the first importance.

ERIC ASHBY

RELATIVITY FOR THE EXPERIMENTALIST

Weltsystem, Weltäther, und die Relativitätstheorie, *by Karl Jellinek. Pp.* xvi + 450. *Wepf and Company, Basel.* 1949. 45 *Swiss francs.*

The author says that most men of science who are primarily experimentalists have only hazy notions about relativity, with a certain amount of uneasiness and confusion; they wonder if it is necessary to unlearn the naïve conceptions of space and time, and whether the question of the existence or non-existence of the aether has been definitely answered. His book is addressed to such readers, and also to philosophers, rather than to the professional theoretical physicists who can understand Eddington's treatise. His aim is something between a work of popularization and a mathematical textbook. With this end in view, he avoids as far as possible the abstract four-dimensional space-time continuum; considerable space is given to a discussion of such topics as the Michelson-Morley experiment, the Kennedy-Thorndike experiment, aberration, and the Fresnel-Fizeau effect. He does not enter deeply into the general theory of relativity, choosing rather to treat specific problems such as the homogeneous gravitation-field and the field of the Sun.

On the historical side the author is weak, his references being often to other textbooks rather than to original papers. However, if the work is not too long for its purpose, it should prove decidedly useful. E. T. WHITTAKER

NUCLEAR INFORMATION CHART

Trilinear Chart of Nuclear Species, *by William H. Sullivan. Art work by Kay Benscoter. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 20*s. net.*

By the artificial synthesis of heavy nuclei, the tally of chemical elements is being pushed towards a hundred; each element has isotopic forms of differing nuclear constitution, and the total number of identified nuclear species is now about nine hundred, most of them being artificially produced and unstable. About some of the nine hundred we know only their nuclear constitution (i.e. the numbers of neutrons and protons they contain), and, for the unstable ones, their mode of radioactive disintegration. For others, detailed information is available on such matters as the exact mass, the nuclear angular momentum, and the energies of particles or photons emitted at disintegration.

It has been customary to summarize the principal properties of atomic nuclei on a chart in which each nuclear species is allotted one square of a gridiron pattern. The position of the square corresponds to the neutron-proton constitution of the nucleus, while numbers and symbols within the square give as many facts about the nucleus as are known, or as can conveniently be compressed into (for example) half a square inch. If a move to the east represents an additional proton and a move to the north an additional neutron, then a beta-transformation between two isobars (nuclei of equal mass number) corresponds to a diagonal move to the south-east. Charts of this kind, compiled by E. Segrè, have set the pattern for most of those hitherto published.

In the chart under review, the neutron and proton co-ordinates are not at right angles but at 60° to one another, beta-transformations being represented by moves in the third direction, at 60° to both the neutron and the proton axes. The spaces are no longer squares of a grid, but hexagons of a honeycomb. Stability or instability, and in the latter case the mode(s) of decay, are shown by colour codes, thus leaving space for a little more numerical and symbolical information. The chart is well printed, but much of the type is too small for easy reading.

The trilinear arrangement tends to equalize the emphasis given to neutron content, proton content, and neutron + proton content of a nucleus, though none of these is quite so clearly displayed as are neutron content and proton content on the usual form of chart. Whether the arrangement is an improvement or not depends upon the user's principal interests, just as Mercator's projection may be either superior or inferior to others for the different uses of a map.

P. B. MOON

HIGH-PRESSURE PHYSICS

The Physics of High Pressure, *by P. W. Bridgman. Pp.* 445, *with various half-tone and line illustrations. G. Bell and Sons Limited, London.* 1950. 35*s. net.*

To the specialist no review of this book is necessary; he will have it. Scientific workers in many fields will find the book stimulating and valuable. Almost anyone with a spark of scientific curiosity will enjoy the account of pioneering effort written by the pioneer. The technical difficulties met and mastered in producing pressures up to 100,000 kg/cm^2 are vividly presented; so is the wonder at the discovery of strange effects. Steel becomes so ductile at 25,000 kg/cm^2 that it shows something like infinite elongation at the neck; many liquids increase their viscosity millions of times and become solids.

The historical introduction is followed by three chapters on technique, followed by separate chapters on the PVT relations in fluids, compressibility of solids, melting phenomena, polymorphic transitions, electrical resistance of metals and solids, thermoelectric phenomena, thermal conductivity, and viscosity. The final chapter is a miscellany which includes the effect of pressure on solubility, the electrical conductivity of solutions, dielectric constant and strength, index of refraction and other optical constants, e.m.f. of a cell, magnetic permeability, rigidity, and Young's modulus. A supplement on recent work concludes the book.

Bridgman's general method is to survey the main effects of pressure on the various physical and chemical properties of matter, to show that theory fails in most cases to predict or explain the whole range of change observed, and to sketch a qualitative theory of his own, for which he makes modest claims. In the end the field is littered with dead theories; Andrade's theory of the variation of viscosity with pressure is a notable exception. The time is ripe, if not overdue, for a new, unifying concept in high-pressure physics.

D. O. SPROULE

NUCLEUS AND ELECTRONS

Interaction entre le Noyau et son Cortège Electronique—Réunions d'études et de mises au point tenues sous la présidence de Louis de Broglie. *Pp.* 198, *with line drawings. Editions de la Revue d'Optique Théorique et Instrumentale, Paris.* 1949. 800 *francs.*

This book contains a series of papers on some interactions between the nucleus and the surrounding electrons of the atom, the best known of which is the phenomenon known as 'internal conversion.' The papers relate to both the theoretical and the experimental sides of these problems, but on the whole the former predominates. The audience which the writers have in view seems to be experimentalists with some theoretical knowledge who wish to gain a better idea of the theory. Louis de Broglie himself contributes an admirable outline of the basic principles, and the first paper, by R. Daudel, extends this to particular problems, making use of de Broglie's new theory of light, which envisages the photon as a particle of small but not zero rest-mass and capable of three states of spin. Space is full of photons 'annihilated' and unobservable, but capable of being called back to life, like electrons from Dirac's sea of states of negative energy. The consequences of this theory, as far as the subject matter of this book is concerned, seem not to differ profoundly from those of the more usual treatment.

The general trend of the book is to point out that the interaction between the central core of the atom, the nucleus, and the electrons which surround it is more varied and less one-sided than is often supposed, and that in particular the absence of some or all of the external electrons may affect the radioactive behaviour of the nucleus. These effects are admittedly small and in some cases open to question, but something of the kind must happen.

G. P. THOMSON

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

ASTRONOMY

The History of Nature, *by C. F. von Weizsäcker. Pp.* 180, *with eight half-tone plates. Routledge and Kegan Paul Limited, London.* 1951. 12*s.* 6*d. net.*

Introducing Astronomy, *by J. B. Sidgwick. Pp.* 259, *with half-tone and line illustrations. Faber and Faber Limited, London.* 1951. 15*s. net.*

The Origin of the Earth, *by W. M. Smart. Pp.* 239, *with many half-tone and line illustrations. Cambridge University Press, London.* 1951. 12*s.* 6*d. net.*

BIOCHEMISTRY

The Biochemistry of Fish—Biochemical Symposia No. 6, *edited by R. T. Williams. Pp.* 105, *with several line diagrams. Cambridge University Press, London.* 1951. 12*s.* 6*d. net.*

BOTANY

Mycotrophy in Plants, *by Arthur P. Kelly. Pp.* 233, *with several line diagrams. Chronica Botanica Company, Waltham, Mass., U.S.A.; Wm. Dawson and Sons Limited, London.* 1950. $4.50 *net.*

The Rhododendron Leaf, *by J. M. Cowan. Pp.* 120, *with colour and half-tone plates. Oliver and Boyd Limited, Edinburgh.* 1951. 21*s. net.*

Seaweeds and their Uses, *by V. J. Chapman. Pp.* 287, *with numerous half-tone and line illustrations. Methuen and Company Limited, London.* 1950. 25*s. net.*

CHEMISTRY

Advanced Organic Chemistry, *by Reynold C. Fuson. Pp.* 669. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1950. 64*s. net.*

Chemical Thermodynamics, *by Frederick D. Rossini. Pp.* 514. *John Wiley and Sons Limited, New York; Chapman and Hall Limited, London.* 1950. 48*s. net.*

Chimie Minérale Théorique et Expérimentale (Chimie Electronique), *by F. Gallais. Pp.* 810, *with* 42 *illustrations. Masson et Cie, Paris.* 1951. *Paper cover,* 2400 *francs; linen cover,* 2800 *francs.*

Colloidal Dispersions, *by Earl K. Fischer. Pp.* 387, *with several line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 60*s. net.*

Fluoreszenz organischer Verbindungen, *by Theodor Förster. Pp.* 312, *with several line diagrams. Vandenhoeck und Ruprecht, Göttingen.* 1951. *Paper cover,* 29.50; *bound,* 32.50 *DM.*

Handbook of Antibiotics, *by A. L. Baron. Pp.* 303. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1951. 52*s. net.*

Les Méthodes d'Analyse des Réactions en Solution, *by G. Charlot and R. Gaugin. Pp.* 328, *with* 242 *figures. Masson et Cie, Paris.* 2200 *francs net.*

Principles of Phase Equilibria, *by F. E. W. Wetmore and D. J. Le Roy. Pp.* 200, *with various line diagrams. McGraw-Hill Publishing Company Limited, London.* 1951. 30*s. net.*

Safety in the Chemical Laboratory, *by H. A. J. Pieters in collaboration with J. W. Creyghton. Pp.* 258, *with various line diagrams. Butterworth's Scientific Publications Limited, London.* 1951. 15*s. net.*

The Solubility of Nonelectrolytes, *by Joel H. Hildebrand and Robert L. Scott. Pp.* 488, *with numerous line diagrams. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 3*rd edition,* 1950. 80*s. net.*

GENERAL SCIENCE

British Journal for the Philosophy of Science, *February* 1951. *Vol. I, No.* 4. *Pp.* 257–340. *Thomas Nelson and Sons Limited, Edinburgh.* 1951. 7*s.* 6*d. net.*

A Century of Science, *edited by Herbert Dingle. Pp.* 338, *with half-tone and line illustrations. Hutchinson's Scientific and Technical Publications, London.* 1951. 15*s. net.*

INDUSTRY

Eyes in Industry, *by D. A. Campbell, W. J. B. Riddell, and A. S. MacNalty. Pp.* 234, *with half-tone and coloured illustrations. Longmans, Green and Company Limited, London.* 1951. 30*s. net.*

Industrial Research in Switzerland, *by Ronald S. Edwards in collaboration with Charles La Roche. Pp.* 111. *Sir Isaac Pitman and Sons Limited, London.* 1951. 21*s. net.*

PHOTOGRAPHY

Progress in Photography 1940–1950. *Editor-in-chief D. A. Spencer. Pp.* 460, *with many half-tone illustrations and line diagrams. Focal Press Limited, London.* 1951. 42*s. net.*

PHYSICS

Conductive Analysis at Radio-Frequency, *by G. G. Blake. Pp.* 109, *with various line diagrams. Chapman and Hall Limited, London.* 1951. 15*s. net.*

Essay in Physics, *by Viscount Samuel. Pp.* 154. *Basil Blackwell, Oxford.* 1951. 7*s.* 6*d. net.*

An Introduction to Servo Mechanisms, *by A. Porter. Pp.* 154, *with numerous line diagrams. Methuen and Company Limited, London.* 1950. 7*s.* 6*d. net.*

Metallurgical Thermochemistry, *by O. Kubaschewski and E. Ll. Evans. Pp.* 368, *with numerous line diagrams. Butterworth-Springer Limited, London.* 1951. 35*s. net.*

The Microphysical World, *by William Wilson. Pp.* 216, *with numerous line diagrams. Methuen and Company Limited, London.* 1951. 5*s. net.*

The Principles of Cloud-Chamber Technique, *by J. G. Wilson. Pp.* 131, *with numerous line diagrams. Cambridge University Press, London.* 1951. 15*s. net.*

A Short History of Radio-Activity, *by T. W. Chalmers. Pp.* 78, *with numerous line diagrams. Published at the offices of* The Engineer, *London.* 1951. 8*s.* 6*d., post free.*

Source Book on Atomic Energy, *by Samuel Glasstone. Pp.* 546, *with half-tone and line diagrams. Macmillan and Company Limited, London.* 1951. 24*s. net.*

TECHNOLOGY

Aspects of the Constitution of Mineral Oils, *by K. Van Nes and H. A. Van Westen. Pp.* 484, *with numerous line diagrams. Elsevier Publishing Company Limited, Amsterdam; Cleaver-Hume Press Limited, London.* 1951. 70*s. net.*

Glass: a Handbook for Students and Technicians, *edited by J. Home Dickson. Pp.* 300, *with numerous half-tone and line illustrations. Hutchinson's Scientific and Technical Publications, London.* 1951. 25*s. net.*

Zinc and Spelter: Notes on the Early History of Zinc, *by J. M. Dawkins. Pp.* 35, *with half-tone and line illustrations. Zinc Development Association, Oxford.* 1950. *No charge.*

ZOOLOGY

Animal Evolution, *by G. S. Carter. Pp.* 368, *with half-tone and line illustrations. Sidgwick and Jackson Limited, London.* 1951. 30*s. net.*

Zoogeography of the Land and Inland Waters, *by L. F. de Beaufort. Pp.* 208, *with several line illustrations. Sidgwick and Jackson Limited, London.* 1951. 30*s. net.*

Notes on contributors

SIR HAROLD SPENCER JONES,

M.A., Sc.D., B.Sc., F.R.S., F.R.A.S.,

Has held the position of Astronomer Royal since the year 1933. He was born in London in 1890 and was educated at Latymer Upper School, Hammersmith, and Jesus College, Cambridge. From 1923 to 1933 he held the post of His Majesty's Astronomer at the Cape of Good Hope. He was knighted in 1943. He has received the Royal Medal of the Royal Society, the Gold Medal of the Royal Astronomical Society, the Janssen Medal of the Astronomical Society of France, the Bruce Gold Medal of the Astronomical Society of the Pacific, and the Gold Medal of the British Horological Institute. He is a past president of the Royal Astronomical Society, of the British Astronomical Association, of the Institute of Navigation, and of the International Astronomical Union. He is president of the British Horological Institute and of the Society for Visiting Scientists. He is a foreign member of many national academies and an honorary member of many Dominion and foreign astronomical societies.

H. J. J. WINTER,

M.Sc., Ph.D., A.Inst.P., F.R.Asiatic S.,

Was born in 1912 and was educated at the City School, Lincoln, University College, Nottingham, and University College, Exeter. He is a member of the History of Science Society and of the British Society for the History of Science. Lecturer in Education (Scientific Method and History of Science) in the University College of the South West, Exeter. He has published many papers on the history of science.

H. BOSCHMA,

D.Sc., F.M.L.S., C.M.Z.S.,

Was born at Ysbrechtum (Holland) in 1893; studied biology at Amsterdam University. Was in the East Indies 1920–2; studied reef corals on islands off Java, and accompanied Dr Th. Mortensen on the Danish Expedition to the Kei Islands. In 1929 and 1930 biologist on the Snellius Expedition in the eastern part of the East Indian Archipelago. In 1939 zoologist on the Netherlands New Guinea Expedition. 1931–4 professor of general zoology in Leiden University; in 1934 became director of the Rijksmuseum van Natuurlijke Historie and professor of systematic zoology in Leiden University. His chief fields of research are reef-corals and rhizocephala.

C. M. YONGE,

D.Sc., F.R.S.,

Is Regius professor of zoology in the University of Glasgow and was previously (1933–44) professor in the University of Bristol. He was born in 1899 and is a graduate of the University of Edinburgh. He served on the staff of the Marine Biological Association at Plymouth between 1924 and 1927, and again from 1930 to 1932. During the intervening period he was Balfour Student at Cambridge and in that capacity led the Great Barrier Reef Expedition to Australia in 1928–9. He has worked at many marine laboratories along the Atlantic and Mediterranean coasts of Europe, on both coasts of North America, at Bermuda, in the Gulf of Mexico (where he did further work on coral reefs), and at Honolulu. He was visiting professor at the University of California, Berkeley, in 1949. He is president of the Scottish Marine Biological Association, chairman of the Supervisory Committee for Brown Trout Research, Scottish Home Department, a member of the advisory committee on fishery research to the Development Commission, of the Executive Committee of the National Institute of Oceanography, of the Fisheries Advisory Committee to the Colonial Office, and of the Nature Conservancy (Scottish Committee).

ERNA GROSSBARD,

B.Sc.

Born in Vienna. Trained at the universities of Vienna, Reading, Cambridge, and London. Began investigations on the production of antibiotics in the soil and the control of plant diseases by microbial antagonism in 1945, when on the staff of the Experimental and Research Station, Cheshunt. This work was carried out for the Agricultural Research Council. Transferred in 1949 to the Botany Department of Imperial College, London, where she is at present continuing the above investigations.

T. A. BENNET-CLARK,

M.A., Ph.D., F.R.S.

Born in Edinburgh in 1903. Educated at Marlborough College and at Trinity College, Cambridge. Assistant to the professor of botany (H. H. Dixon), Trinity College, Dublin, 1924–30. Since then he has held a lectureship in Manchester University and two chairs of botany at Nottingham and now at King's College, London. His research interests lie in plant physiology, and in particular in the study of the interrelationships of respiration and secretory or accumulation mechanisms.

H. ROXBEE COX,

Ph.D., D.I.C., B.Sc., M.I.Mech.E., F.R.Ae.S., F.Inst.F., F.I.Ae.S.

Born 1902; educated at King's Norton School and the Imperial College of Science and Technology. Chief Technical Officer, Royal Airship Works, 1931; Principal Scientific Officer, Aerodynamics Dept., Royal Aircraft Establishment, 1935–6; Head of Air Defence Dept., R.A.E., 1936–8; Chief Technical Officer, Air Registration Board, 1938–9; Superintendent of scientific research, R.A.E., 1939–40; deputy director of scientific research, Ministry of Aircraft Production, 1940–3; director of special projects, Ministry of Aircraft Production, 1943–4; chairman and managing director of Power Jets (Research and Development) Ltd., 1944–6; director of the National Gas Turbine Establishment, 1946–8. A governor of the College of Aeronautics; member of the Aeronautical Research Council, 1944–8. Past president of the Royal Aeronautical Society. Chief scientist, Ministry of Fuel and Power, since 1948. Publications: numerous papers on theory of structures, wing flutter, gas turbines, civil aviation, and airships.

MEIRION THOMAS,

M.A., F.R.S.E., F.R.S.

Born 1894. Educated Friars' School, Bangor, University College of North Wales (1912–14), and Trinity Hall, Cambridge (1919–24). Since 1924 at Armstrong College (now King's College), Newcastle upon Tyne, first as lecturer in botany, then as reader in plant physiology, and now as professor of botany. Publications: *Textbook on Plant Physiology;* papers on carbohydrate catabolism with alcohol accumulation (zymasis) and the bearing of zymasis on certain physiological diseases of apples, and, more recently, papers on crassulacean acid metabolism.

ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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British contributions to science, 1851–1951

PART TWO

The account given in our July issue of some British contributions to science during the century between the Great Exhibition of 1851 and the Festival of Britain in 1951 dealt mainly with astronomy, physics, and biology. The period includes also many notable achievements of British scientists in all departments of chemistry. It comprises, for example, the first recognition of valency—by Edward Frankland in 1852. During the earlier part of the period, this idea was for the most part applied in organic chemistry, but it served, too, as a unifying principle in the study of elements other than carbon. It gradually became clear, however, that the simpler views of valency which rendered such valuable service in organic chemistry were insufficient in the remaining field, and here the theory of co-ordination compounds, proposed by Alfred Werner of Zürich in 1893, acted as a guide. Significant contributions to the study of such compounds were made in the 1920's by Sir Gilbert Morgan, and an explanation of their structure in terms of the electronic theory was given by N. V. Sidgwick, who employed with much success the conception of a co-ordinate link as a special case of an ordinary valency bond. Cognate with theories of valency is the classification of the elements, and we may recall the tentative gropings towards the periodic system made by W. Odling and J. A. R. Newlands.

One of the most successful British workers in the realm of inorganic chemistry was Sir Henry Roscoe, whose researches on vanadium are models of chemical investigation. Sir William Crookes made an intensive study of the rare earths, and in 1861 discovered thallium. Later in the period came the romantic story of the discovery in the atmosphere of a whole family of new elements—the inert gases—as a result of the brilliant work of the third Lord Rayleigh, Sir William Ramsay, M. W. Travers, and others.

From the time of Davy and Faraday, physical chemistry has always had a strong attraction for British chemists. Chemical kinetics has been a favourite subject with them and is therefore selected for special mention here. In 1866, a year before the satisfactory enunciation of the law of mass action by the Norwegians C. M. Guldberg and P. Waage, the underlying idea had been used in a particularly noteworthy study by A. G. V. Harcourt and W. Esson at Oxford; their work may be said to have formed the basis, both in theory and in experiment, of the modern science of chemical kinetics. On the experimental side, useful contributions were made by J. H. Gladstone and the Irish scientist J. H. Jellett, while in the difficult region of gas reactions the work of H. B. Dixon, begun in 1884, was of fundamental importance. Incidentally, it may be remarked that Dixon's discovery of the curious influence of water on many chemical reactions, a discovery ably pursued by his pupil H. B. Baker, had considerable effect on theoretical views on catalysis. The study of gaseous explosions by Dixon was continued by W. A. Bone and R. V. Wheeler and is still engaging the attention of other British chemists. Our knowledge of chemical kinetics in general has in more recent years been advanced by such workers as Sir Cyril Hinshelwood and E. A. Moelwyn-Hughes, who have not only greatly added to the experimental data but have suggested theories commanding wide support.

Roscoe did not confine his interest to inorganic chemistry alone; he conducted much research on physico-chemical problems. His experiments on liquid solutions were of great accuracy, but it is perhaps his study of the action of light on chemical changes which is best known in this field. Early work on the action of light on the combination of hydrogen and chlorine was done by Dalton and by J. W. Draper (an Englishman who emigrated to America), but the work of R. W. Bunsen and Roscoe, begun in 1855, was in effect the foundation-stone of modern photochemistry. Photochemical work has been actively continued in Britain ever since.

The wide domain of colloid chemistry, opened by the pioneer researches of Thomas Graham, has been cultivated with conspicuous success by many later British chemists. Of outstanding workers on the subject, mention may be made of S. E. Linder and H. W. Picton, Sir William Hardy, and Sir Eric Rideal. Rideal, J. W. McBain, and N. K. Adam have also made notable contributions to the study of adsorption.

Limitations of space preclude a description of the part played by British workers in the development of other branches of physical chemistry, such as electrochemistry, thermochemistry and thermodynamics, and the phase rule, but it is not too much to say that it has won equal success.

A century ago, the development of organic chemistry had reached a particularly interesting stage. The fundamental problem of organic molecular constitution was approaching a solution. Liebig's earlier view of organic chemistry as the chemistry of compound radicals led up through many stages to the idea of mixed types, based by A. W. Williamson on work on ethers (1850–2). Frankland's theory of valency, already mentioned, was soon followed by A. Kekulé's recognition, in 1858, of the quadrivalency of carbon and the linking of carbon atoms. These ideas, and the related theory of organic molecular structure, were entertained simultaneously by the neglected Scottish chemist A. S. Couper. Both Kekulé and Couper put forward representations of organic molecules which bear a close resemblance to modern structural formulae. Crum Brown introduced graphic formulae in 1865, showing each individual valency bond. These structural representations of organic molecules, arising partly from the work and ideas of British chemists, have been mainly responsible for the amazing developments of pure and applied organic chemistry in the succeeding period.

In 1856, W. H. Perkin senior (later Sir William) obtained mauveine when trying to prepare quinine artificially. He later built the first dyestuffs factory, and the latent possibilities of coal tar as a source of unending synthetic dyes, perfumes, and fine chemicals of many kinds soon became apparent. The consequent flood of successful research was guided by the theory of organic molecular structure that had synchronized so closely with Perkin's original discovery.

In Britain, the development of organic chemistry owed much at this time to chemists who had been trained, between 1846 and 1864, at the Royal College of Chemistry, London, under the direction of A. W. Hofmann. Hofmann pictured England as becoming 'the greatest colour-producing country in the world,' but the temporary support of chemistry died down, and Hofmann left London for Berlin in 1864. Not until the war of 1914–18 came a public realization of the importance to Britain of a strong organic chemical industry, with a particular emphasis on the key industry of organic dyes.

In the half-century between Hofmann's departure and the first world war there was a remarkable expansion of academic organic chemistry, in which British chemists, although receiving little encouragement, played a worthy role. Among these investigators, most of whom occupied professorial chairs, such typical representatives come to mind as H. T. Brown in the chemistry of brewing, R. Meldola in the chemistry of dyes, W. H. Perkin junior in the terpene and alkaloid fields, F. S. Kipping in the organic chemistry of silicon, Sir Arthur Harden in bacterial chemistry, Sir William Pope in stereochemistry, and Sir James Irvine and Sir Norman Haworth in sugar chemistry.

In the subsequent period, astonishing progress has been made in these and other fields of organic chemistry. As illustrations of the outstanding achievements of British chemists it is sufficient to mention the contributions of contemporary workers, among whom Sir Robert Robinson is pre-eminent, in such diverse fields as the chemistry of alkaloids, anthocyanins, terpenes, steroids, sugars, complex carbohydrates, vitamins, natural pigments, synthetic dyes, phthalocyanines, high polymers, acetylenic compounds, stereochemistry, and the electronic interpretation of organic reactions.

Sir Frederick Gowland Hopkins' work on vitamins (1906–12) opened up a vast new field of primary importance, to which other British workers have made contributions of high value, including the first synthesis of a member of this class, vitamin C (1933). The discovery of adrenaline, the first hormone to be synthesized, may be traced back to the work of Sir Edward Schaefer and G. Oliver, in 1894, on the medulla of the adrenal gland. Sir William Bayliss and E. H. Starling's original recognition of a hormone (1902), the successful study by British investigators of the pituitary (1909) and thyroid (1914) hormones, and the isolation (1921) and manufacture of insulin, are landmarks in the development of this second field, in which the sex hormones and cortisone have provided new centres of interest. In a third field, original British work by Sir Alexander Fleming (1929) on the inhibiting effect of moulds on the growth of organisms, culminating in the British isolation and investigation of penicillin by Sir Howard Florey and E. Chain and the Anglo-American achievement of its commercial production during the second world war, has led to the study of streptomycin and other natural antibiotics of much significance in chemotherapy.

In the domain of synthetic drugs and chemotherapeutic agents, the earlier success of novocaine has been matched more recently by the elaboration in Britain of the sulphonamides, of Paludrine, and of an effective antidote to mustard gas. These achievements are to be welcomed as heralds of the approach of a rational system of therapeutics.

Carotenoids and vitamin A—the end of a chapter

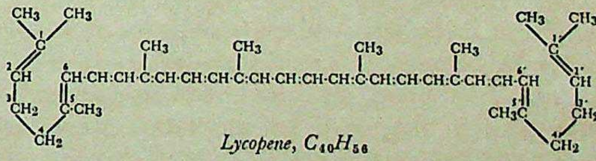
SIR IAN HEILBRON and A. H. COOK

The carotenoid pigments have excited attention from the very beginning of organic chemistry. The interest attached to many of them is heightened by their structural relationship to vitamin A and their probable role in living cells. A period of descriptive and analytical examination of the carotenoids has now reached a culminating point with the complete synthesis of vitamin A and of representative carotenoid pigments. The present article completes the story begun by Professor Paul Karrer in ENDEAVOUR, 7, 3, 1948.

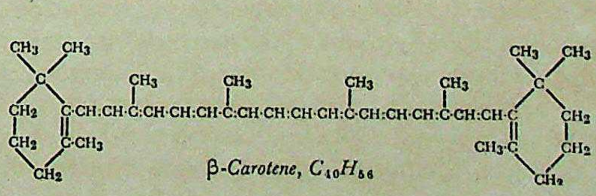
The carotenoids are, with few exceptions, highly unsaturated fat-soluble orange or yellow pigments. Representatives of them are widely distributed in nature. Typical substances of the class are the isomeric hydrocarbon pigments occurring in the carrot and elsewhere (carotenes), or in the tomato (lycopene), and pigments of different degrees of oxygenation such as cryptoxanthin, zeaxanthin, and lutein (xanthophyll), associated with the colours of the orange, maize, and egg-yolk respectively. Exceptional carotenoids include the water-soluble glycoside crocin, present in the yellow stamens of the crocus, and the blue protein-adduct ovoverdin, or astacene, occurring in lobster-shell.

As recently as two decades ago, the chemistry of this group was practically confined to knowledge of the molecular formulae of carotene, $C_{40}H_{56}$, which had been shown to consist of a mixture of isomerides, and of a few closely related representatives containing oxygen. That the ensuing years have revealed an exceptionally detailed picture of this field has been due to the development of microanalytical techniques, and the application of chromatographic adsorption. As a result, between eighty and one hundred structurally distinct natural carotenoids have so far been recognized; in addition many are known to be capable of assuming stereoisomeric forms, some of which, notably those of lycopene, are encountered in nature. The detailed chemistry of some of these pigments has previously been reviewed in this journal [1], so that only salient and novel features warrant attention in this account. Disregarding a few esters, such as the widely distributed heleniene, which is a dipalmitate of lutein, all the known carotenoids contain either 40 carbon atoms or a lesser number which can, in most if not all cases, be structurally related to the number in the more complex compounds. The constitutions of a few typical carotenoids are shown below; these illustrate the regular pattern of isoprene units and the polyene systems, mostly conjugated, which are characteristic features of the more complex carotenoids and which can be related to the structures of the simpler representatives. It will be seen that lycopene and β-carotene are isomeric, and that zeaxanthin and β-carotene have identical structures except for two hydroxyl groups characterizing the former. Such relations are common throughout the whole group of carotenoids. For example, α-carotene differs from β-carotene only in the transposition of one double bond from the 5:6 to the 4:5 position, putting it out of conjugation with the remainder of the polyene system; this feature is associated with the optical activity of the α-isomeride. Again, cryptoxanthin, $C_{40}H_{56}O$, contains only one of the two hydroxyls of zeaxanthin and is thus constitutionally intermediate between that compound and β-carotene; lycoxanthin, $C_{40}H_{56}O$, bears exactly the same relation to lycopene as cryptoxanthin does to β-carotene.

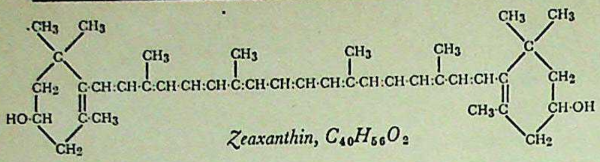
While it is unnecessary in the present article to attempt to detail the intricate work which led to the acceptance of these and many related structures, it is of more than passing interest to recall



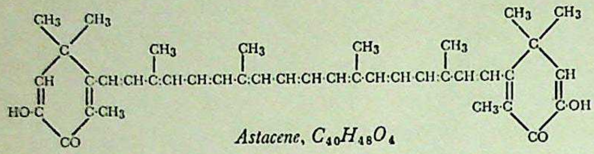
Lycopene, $C_{40}H_{56}$



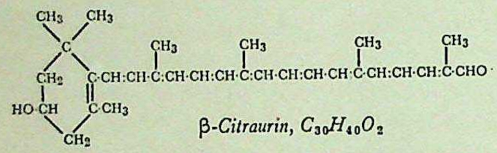
β-*Carotene*, $C_{40}H_{56}$



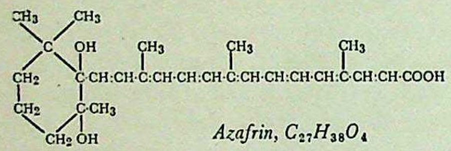
Zeaxanthin, $C_{40}H_{56}O_2$



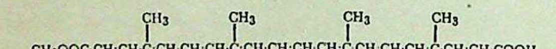
Astacene, $C_{40}H_{48}O_4$



β-*Citraurin*, $C_{30}H_{40}O_2$

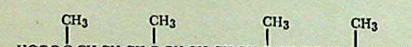


Azafrin, $C_{27}H_{38}O_4$



$$\mathrm{CH_3OOC{\cdot}CH{:}CH{\cdot}\overset{CH_3}{\overset{|}{C}}{:}CH{\cdot}CH{:}CH{\cdot}\overset{CH_3}{\overset{|}{C}}{:}CH{\cdot}CH{:}CH{\cdot}CH{:}\overset{CH_3}{\overset{|}{C}}{\cdot}CH{:}CH{\cdot}CH{:}\overset{CH_3}{\overset{|}{C}}{\cdot}CH{:}CH{\cdot}COOH}$$

Bixin, $C_{25}H_{30}O_4$

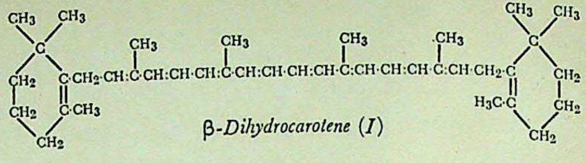


$$\mathrm{HOOC{\cdot}\overset{CH_3}{\overset{|}{C}}{:}CH{\cdot}CH{:}CH{\cdot}\overset{CH_3}{\overset{|}{C}}{:}CH{\cdot}CH{:}CH{\cdot}CH{:}\overset{CH_3}{\overset{|}{C}}{\cdot}CH{:}CH{\cdot}CH{:}\overset{CH_3}{\overset{|}{C}}{\cdot}COOH}$$

Crocetin, $C_{20}H_{24}O_4$

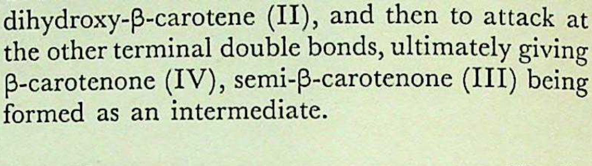
that the polyene system as it occurs in the carotenoids remains one of largely unknown potentialities. A glimpse of the chemical reactivity of this grouping is, however, afforded by several reactions which have come to light incidentally.

For example, while the highly unsaturated, conjugated chain is—not unexpectedly—very sensitive to air and other oxidizing agents, as well as to reducing agents, restrained reductive or oxidative attack may lead to controlled structural alteration at specific points. Thus, reduction of β-carotene in ethereal solution by means of aluminium amalgam leaves the terminal di-tertiary double bonds unaffected, but adds a hydrogen atom to each end of the residual conjugated system to give a β-dihydrocarotene (I) [2], a substance which has recently been synthesized:

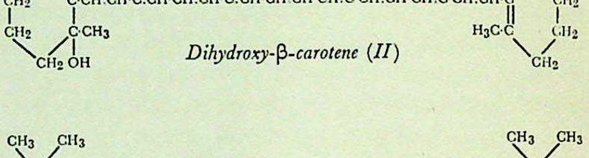


β-*Dihydrocarotene* (*I*)

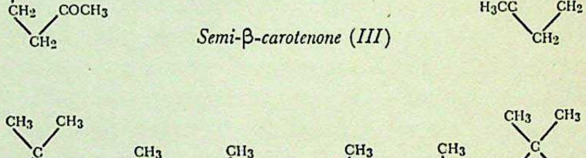
On the other hand, controlled oxidation by means of chromic acid leads first to attack at one of the double bonds in the ring, with the formation of dihydroxy-β-carotene (II), and then to attack at the other terminal double bonds, ultimately giving β-carotenone (IV), semi-β-carotenone (III) being formed as an intermediate.



Dihydroxy-β-*carotene* (*II*)

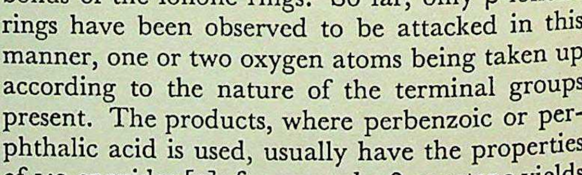


Semi-β-*carotenone* (*III*)

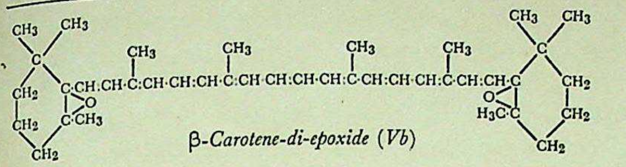


β-*Carotenone* (*IV*)

It is worth recalling that it was an extension of such reactions which led to the recognition of the structural relationship between β-carotene on the one hand, and azafrin, as well as bixin and certain other carotenoids, on the other. Still more significant, perhaps, was the discovery that oxidation of carotenoids by per-acids results in many instances in the addition of oxygen to the double bonds of the ionone rings. So far, only β-ionone rings have been observed to be attacked in this manner, one or two oxygen atoms being taken up according to the nature of the terminal groups present. The products, where perbenzoic or perphthalic acid is used, usually have the properties of 1:2-epoxides [3]; for example, β-carotene yields both a mono- (Va) and a di-epoxide (Vb):



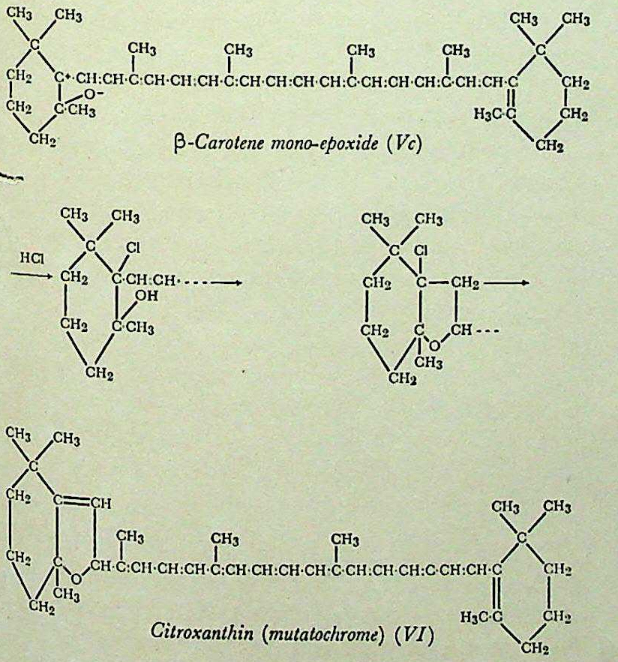
β-*Carotene-mono-epoxide* (*Va*)



β-*Carotene-di-epoxide* (*Vb*)

It is probably significant for the understanding of the biological role of the carotenoids that several naturally occurring pigments, such as trollixanthin [4], have been shown to be epoxides. Again, antheraxanthin, one of the characteristic pigments of the anthers of *Lilium tigrinum*, is indistinguishable from zeaxanthin mono-epoxide; violaxanthin from the yellow pansy is identical with zeaxanthin di-epoxide.

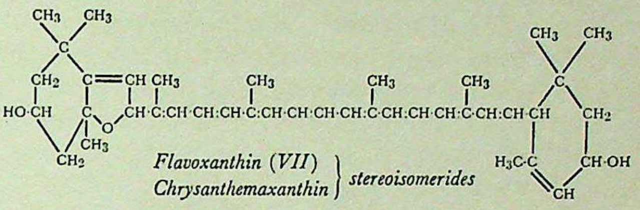
The carotenoid epoxides are very sensitive to mineral acids, a fact which has suggested that the normal epoxide formulation may advantageously be replaced by a polar representation, as in Vc. When carotene mono-epoxide is treated with hydrogen chloride it is converted partly into β-carotene, but to a major extent into another pigment called mutatochrome; this is a substance identical with the citroxanthin (VI) which occurs in orange-peel [5]. Mutatochrome contains a fused furanoid structure, and the origin of the latter is most easily understandable on the basis of the modified epoxide formulation indicated below:



β-*Carotene mono-epoxide* (*Vc*)

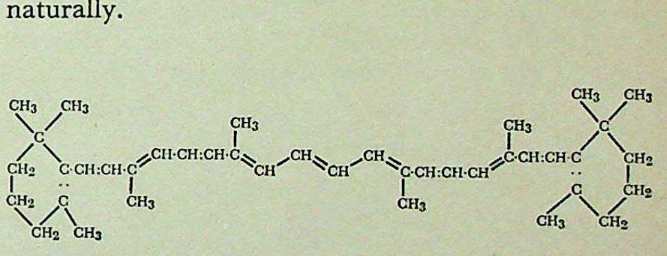
Citroxanthin (*mutatochrome*) (*VI*)

Presumably the furanoid carotenoids, like the epoxides, are also widely distributed in nature. Auroxanthin, a pigment of the yellow pansy, is the difuranoid compound structurally derived from zeaxanthin di-epoxide, while flavoxanthin (VII), the pigment of the flowers of the dandelion, is similarly related to the mono-epoxide of lutein, as also is chrysanthemaxanthin, present in gorse flowers; the latter pigment therefore appears to be stereoisomeric with flavoxanthin.



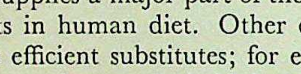
Flavoxanthin (*VII*)
Chrysanthemaxanthin } *stereoisomerides*

The symmetrical formula of β-carotene contains eleven double bonds, of which it is concluded, on theoretical grounds, that only five, as indicated by full lines in the formula below, are capable of adopting more than one configuration [6]. These are depicted in the formula as having a uniformly *trans*-configuration, but a considerable number of *cis*-configurations may be foreseen. In fact, β-carotene and many other carotenoids have been artificially obtained in several of the possible forms, and several *cis*-carotenoids are known to occur naturally.



The carotenoids are primarily plant pigments; as far as is yet known the animal organism is unable to synthesize materials of this class, or to do more than effect limited modifications in the structures of those members of it which are ingested. Despite this fact, more is known of the significance of certain carotenoids in the animal kingdom than of their importance to plant life. The universal occurrence of the carotenes and other carotenoids—singly or as mixtures—in green leaves has led to suggestions that these pigments play some essential part in photosynthesis. Again, the appearance of unusual carotenoids in individual organs, such as that of α-carotene in the spermatozoids of *Fucus* species, has prompted the suggestion that the pigmentation is associated with the motility or the chemotactic sensitivity of the gametes [7]. In the latter connection, the ready formation of epoxides by many carotenoids, and the ease with which the epoxide oxygen atom is lost, inevitably stimulate speculation on a possible mechanism of oxygen transport. In a fascinating series of experiments, Kuhn and Moewus have drawn attention to the part which appears to be played by crocin, *cis-* and *trans*-crocetin, and several related substances, in conditioning the fertility and in bringing about the fertilization of the gametes of selected *Chlamydomonas* species [8]. Many of the above suggestions, however, are either without adequate experimental foundation or pose more queries than they seem to answer.

In the animal kingdom a close connection between carotene and a growth factor was suspected more than thirty years ago, and as the chemistry of the fat-soluble vitamins evolved it became apparent that a relationship existed between carotene and vitamin A [9]. Later, it was shown that pure β-carotene could act as a substitute for vitamin A_1, and it is now recognized that, in fact, β-carotene supplies a major part of the vitamin A requirements in human diet. Other carotenoids may be less efficient substitutes; for example, α- and γ-carotenes have only half the effectiveness of the β-isomer, a relation upon which recent work has thrown light [10]. Vitamin A_1 has been shown to have structure (VIII), and a relationship between this structure and those of the known carotenoid provitamins may be clearly discerned.



Vitamin A_1 (VIII)

Thus, formally, two molecules of vitamin A_1 may be considered as arising from the hydrolytic fission of β-carotene:

$$C_{40}H_{56} + 2H_2O \rightarrow 2C_{20}H_{29}OH.$$

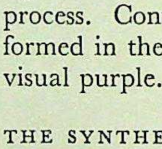
A similar fission of α- or γ-carotene, or indeed of any carotenoid containing an unsubstituted β-ionone ring, could, formally, lead to the formation of only one molecule of vitamin; the latter requirement is encountered, for example, in cryptoxanthin, which actually has only half the effectiveness of β-carotene as a provitamin A_1. These comparatively simple relationships are, incidentally, affected by the steric configurations of the carotenoids concerned, *cis*-isomers proving to be less effective than parent compounds entirely *trans*.

The conversion of β-carotene into vitamin A_1 has been realized experimentally, but despite the apparent simplicity of the change concerned, no results capable of being utilized on a large scale have so far emerged [10]. The desirability of directly synthesizing vitamin A_1 industrially, to supplement that available from fish-liver oils, is therefore a very important problem. During very recent years, this synthesis has been achieved by the ingenuity of the organic chemist, notably by methods involving the use of acetylenic intermediates. It is not surprising that suitable extension of the same methods has led also to the synthesis of a variety of carotenoids; some impression, necessarily brief, of these developments is given in the latter part of this article.

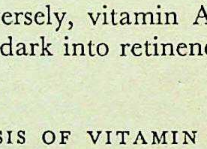
Before finally leaving the question of the physiological significance of the carotenoids, mention must be made of their part in the process of vision. Though their detailed role is still unelucidated, it has been found that visual purple (rhodopsin) is a protein-retinene complex from which, on exposure to light, the retinene component is liberated. Constitutionally, this component is the aldehyde corresponding to vitamin A_1, into which it is converted [11] in the visual process. Conversely, vitamin A_1 becomes transformed in the dark into retinene and thence into visual purple.

THE SYNTHESIS OF VITAMIN A_1

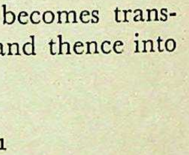
The two obvious starting materials for any synthesis of the vitamin are β-cyclocitral and β-ionone (IX); only the latter has proved sufficiently reactive to be useful. The first synthesis of impure vitamin A_1 was achieved in 1937 by converting (IX) into the C_{15} aldehyde (X) and thence, by condensation with β-methylcrotonaldehyde, into vitamin A_1 aldehyde, from which the vitamin itself was obtained on reduction [12]. This method leaves much to be desired, and far more fruitful has been the exploitation of the related C_{14} aldehyde (XI) obtained as the ultimate result



(*IX*)

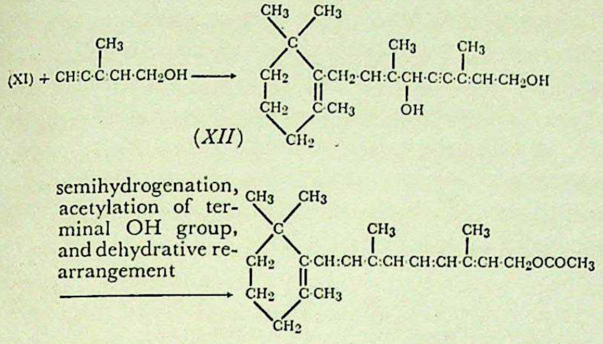


(*X*)



(*XI*)

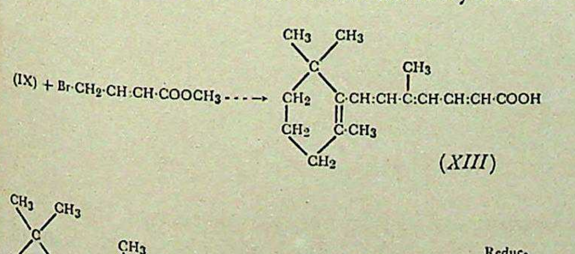
of condensing β-ionone with ethyl chloracetate. It was thought [13] that condensation of this aldehyde with 3-methylpent-2-en-4-yn-1-ol (XII) perhaps offered a route to the vitamin by steps such as the following:


(XI) + CH:C·C·CH·CH₂OH
(XII)
semihydrogenation, acetylation of terminal OH group, and dehydrative rearrangement

Vitamin A acetate

At the time of these suggestions (1942) the feasibility of the projected reactions had been foreshadowed, but a considerable volume of exploratory work on the preparation and reactions of acetylenic intermediates had still to be carried out. Ultimately, in 1946, the synthesis was realized, thanks in great measure to an intensive study of the reactions leading to the key intermediate (XI). A crystalline alcohol identical in all respects with the natural vitamin was eventually obtained [14]. It may be pointed out that this type of synthesis is applicable to a variety of isomerides, analogues, and derivatives of the vitamin, and that several of these have in fact been prepared.

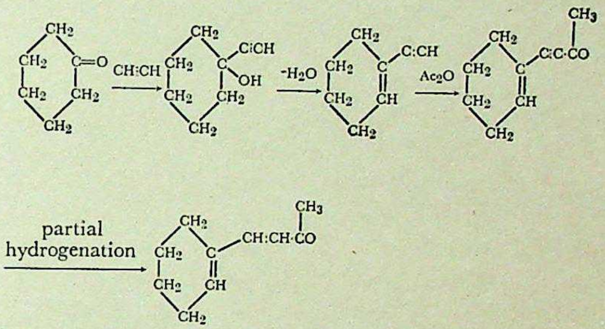
Another series of reactions, using β-ionone as the starting material, includes its condensation with methyl γ-bromocrotonate to give ultimately the C_{17} acid (XIII) and thence, by means of dimethyl-cadmium or methyl-lithium, the C_{18} ketone (XIV). A second Reformatsky reaction, using ethyl bromacetate, then yields vitamin A_1 acid [15]; thence the vitamin itself is obtained by reduction with lithium aluminium hydride.



(XIV)

Vitamin A_1 acid is of particular interest because, although its biological activity is comparable with that of the vitamin itself [16], it does not appear to be stored in the liver.

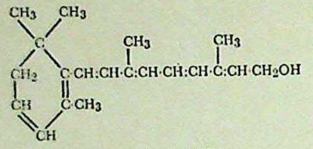
The preceding syntheses, flexible though they are, obviously do not permit of varying the structure in the β-ionone part of the molecule. This can be accomplished only by starting with synthetic analogues of β-ionone. Perhaps the most useful of such approaches so far devised consists in the dehydration under selected conditions of ethynylcyclohexanol or its substituted derivatives, followed by Grignard condensation of the product with acetic anhydride:



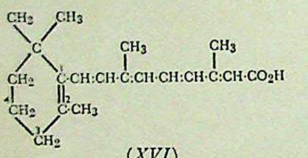
Application of the methods outlined earlier, or of extensions of them, has provided a variety of vitamin A_1 analogues, though the biological activity of the products was exceedingly small [16].

VITAMIN A_2

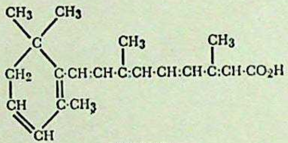
It has been recognized for some years that the liver oils of fresh-water fish contain, in addition to vitamin A_1, a second vitamin of similar structure, now known as vitamin A_2. Several conjectures were made as to the structure of the latter vitamin, though precise work was difficult or impossible in the absence of pure material; even in very recent years there has been no agreement on the empirical formula of the compound. An early suggestion that it may be represented as a 3-dehydrovitamin A_1 (XV) has now received unexpectedly ready confirmation [17]. Vitamin A_1 acid (XVI), in the form of its methyl ester, gave a 3-bromo-derivative on treatment with N-bromosuccinimide. This product readily suffered dehydrobromination, and on reducing the free acid (XVII) with lithium aluminium hydride an oil was obtained which, in physical and general chemical properties, was virtually indistinguishable from vitamin A_2. For example, on oxidation it was converted into a retinene$_2$ which showed light absorption similar to that of a retinene$_2$ prepared from natural vitamin A$_2$; it seems, however, that the incidence of *cis-trans* isomers hinders any simple identification of the aldehydes, or indeed of the parent alcohols. It is interesting to recall that in the case of vertebrates utilizing vitamin A$_2$ the part of retinene$_1$ is played by retinene$_2$ or vitamin A$_2$ aldehyde; in these instances also the visual purple consists of a protein complex, porphyropsin, of vitamin A$_2$ aldehyde [18].



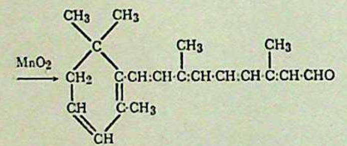
Vitamin A$_2$ (XV)



(*XVI*)



(*XVII*)



Retinene$_2$

THE SYNTHESIS OF CAROTENOIDS

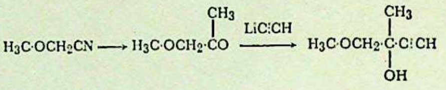
The synthesis of structures of the complexity and sensitivity of the carotenoids offers an immediate challenge to the ingenuity of the chemist. It is clear, especially when the symmetrical structures of β-carotene and certain other carotenoids are considered, that many of the approaches to vitamin A already outlined offer possible synthetic routes to the pigments themselves, and it has been pointed out [19] that a number of possibilities present themselves for the elaboration of the C$_{40}$ skeleton. For example, limiting attention to intermediates whose preparation has already been effected, or for which preparations might be devised without great difficulty, the elaboration of β-carotene may be envisaged as proceeding in the following steps:

$$C_{14} + C_5 \rightarrow C_{19}; \qquad 2C_{19} + C_2 \rightarrow C_{40}.$$

A second approach is represented by:

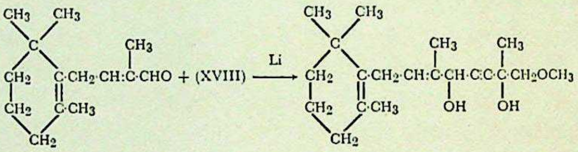
$$C_{13} + C_3 \rightarrow C_{16}; \qquad 2C_{16} + C_8 \rightarrow C_{40}.$$

In the first of these possibilities the C$_{14}$-aldehyde which had already figured prominently in the synthesis of vitamin A$_1$ promised to be the most satisfactory starting material. We need not detail the arguments leading to the selection of the C$_5$ component, but the aldehyde, on condensation with the carbinol (XVIII), did in fact afford the diol (XIX), which was semi-hydrogenated and the product smoothly dehydrated. From the resulting mixture there was isolated a vinyl ether (XX), treatment of which with dilute acid afforded the desired C$_{19}$ aldehyde (XXI):

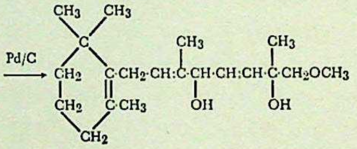


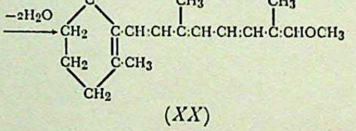
$$H_3C{\cdot}OCH_2CN \longrightarrow H_3C{\cdot}OCH_2{\cdot}\overset{CH_3}{\overset{|}{C}}O \xrightarrow{LiC:CH} H_3C{\cdot}OCH_2{\cdot}\underset{\underset{OH}{|}}{\overset{\overset{CH_3}{|}}{C}}{\cdot}C{:}CH$$

(*XVIII*)

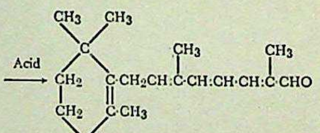


(*XIX*)



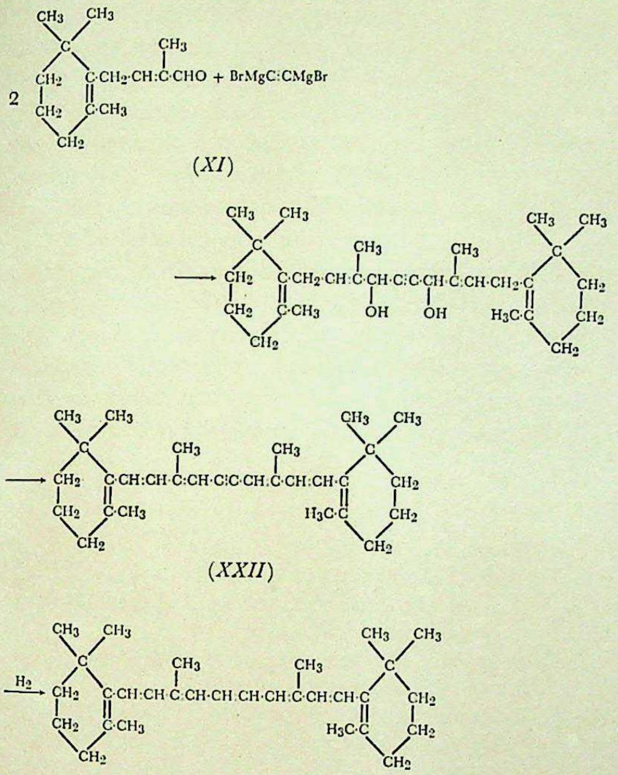


(*XX*)



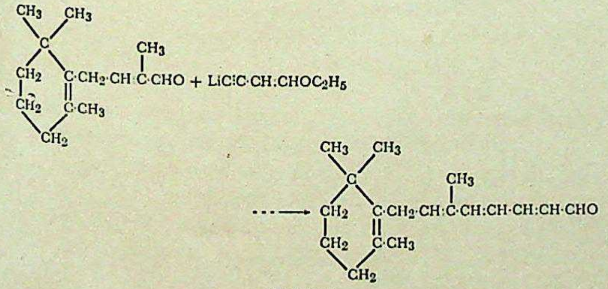
(*XXI*)

Unsaturated aldehydes, simpler than, but comparable with, (XXI), had already been doubly condensed with the *bis*-Grignard reagent derived from acetylene. For example, two molecules of the C$_{14}$ aldehyde (XI) and one of acetylene had afforded the C_{30} hydrocarbon (XXII), while the C_{18} aldehyde (XXIII) similarly yielded a C_{38} hydrocarbon. Direct or indirect hydrogenation of these acetylenic compounds converted them into the completely conjugated ethylenic hydrocarbons of carotenoid character [20] such as (XXIV).

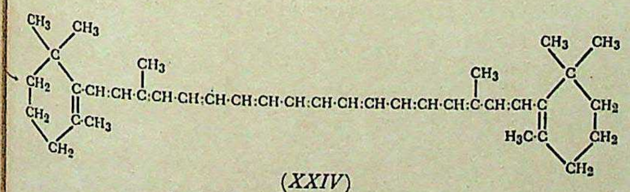


(*XI*)

(*XXII*)

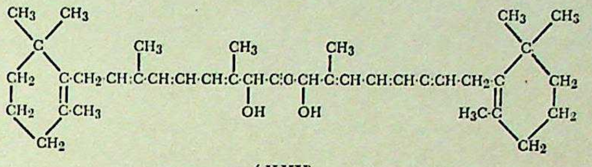


(*XXIII*)



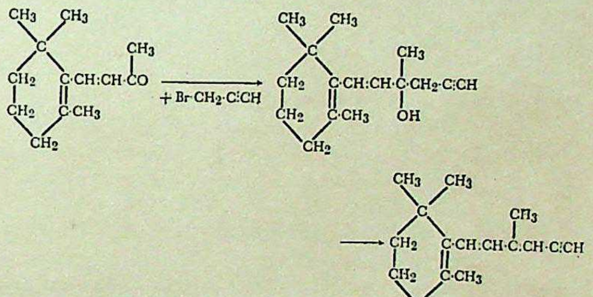
(*XXIV*)
(7:7)-*Bis-desmethyl-β-carotene*) [21]

The way was now clear for the new C_{19} aldehyde (XXI) to be condensed with acetylene dimagnesium bromide to give primarily the C_{40} diol (XXV); ultimately β-carotene, identical in all respects with the natural pigment, was obtained [22]:

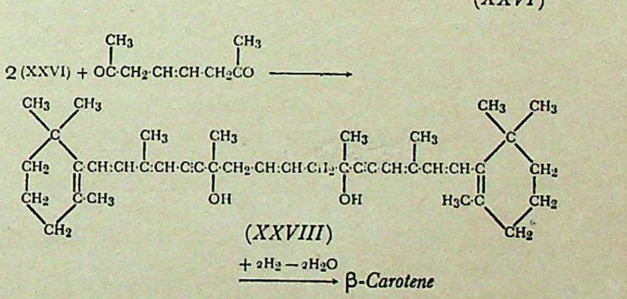


(*XXV*)

The alternative approach to the carotene structure, mentioned above, has also been realized in the following manner. The C_{16} component was the acetylenic hydrocarbon (XXVI) derived from β-ionone, two molecules of which were condensed with 4-octene-2:7-dione (XXVII) [23] to give the C_{40} di-ine diol (XXVIII). In the now familiar way, addition of hydrogen to the two acetylenic groups, followed by dehydration, again afforded β-carotene:



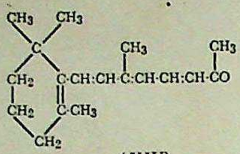
(*XXVI*)



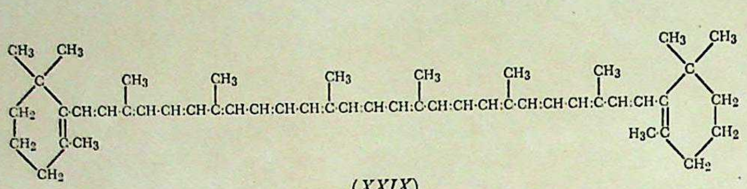
(*XXVIII*)

A similar series of reactions, beginning with the open-chain γ-ionone, has provided a complete synthesis of lycopene [24], while γ-carotene and α-carotene have likewise been obtained from appropriate starting ketones.

The flexibility of these syntheses has paved the way to a variety of artificial carotenoid pigments. For example, by beginning not with α- or β-ionone but with the analogous C_{18} ketone (XIV), hydrocarbons with 15 conjugated double bonds have been prepared, as in 'decapreno-β-carotene' (XXIX) [25]:



(*XIV*)



(*XXIX*)

CONCLUSION

The striking results here briefly described bring to a close one of the most fascinating stories in the chemistry of natural substances. The opening phases take us back more than a century, for various aspects of the study of carotenoids have claimed the attention of outstanding scientists from the time of Berzelius. Recently, however, the chemistry of natural polyene compounds has assumed a new appearance. The picture, from the chemical, and particularly from the synthetic, standpoint, was formerly one of increasing complexity; now, largely as a result of intensive study of the potentialities of acetylenic chemistry, the major synthetic problems have been overcome, and, with the conclusion of this phase, attention will undoubtedly be increasingly directed to the role of these substances in the living cell. The organic chemist has had success; now perhaps it will be the turn of the biochemist to uncover a further section of the picture. It may be that a glimpse of this new chapter is already afforded by recent work on the isolation of 5-ketotetrahydroionone and related compounds from urine [26] since it seems that they are transformation products of carotenoid precursors.

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Sexual dimorphic colour characters in animals

H. G. VEVERS

The morphogenetic processes underlying the secondary sexual differences of colour in animals, which have long been recognized as playing an important part in the evolution of species, have received much attention in recent years. Two distant types of coloration have been shown to be involved, one due solely to pigment and the other to refractive effects. Coloration may, in some cases, be under direct genetic control; in others, hormones play a decisive part, so that often male coloration can be induced in females, and *vice versa*.

The selective value of sexual dimorphic characters has been the subject of much discussion since the postulation by Darwin [4] of a theory of sexual selection, and the subject was considerably clarified by the valuable analysis of J. S. Huxley [6]. The discussion is concerned primarily with the means by which sexual dimorphic characters have developed during the evolution of a species. In recent years, however, there has been much work on the elucidation of morphogenetic processes responsible for the development of such characters during the life of an individual. These processes are necessarily closely linked with those involved in the general field of sex determination and sex differentiation.

Sexual dimorphism in animals is usually expressed in differences between the sexes in the colour, shape, or size of various external organs. It is difficult to draw a satisfactory distinction between this type of sexual dimorphic character and those, such as claspers and various types of copulatory organs, which are directly concerned with mating and gamete conjugation; these two groups are often conveniently termed secondary sexual and accessory sexual characters respectively. The present discussion is restricted to the phenomenon of secondary sexual differences in colour.

Colour in animals is most commonly caused by the reflection of incident light of certain wavelengths from a layer of pigment deposited in the surface tissues; this type of reflection gives normal pigmentary colours. There are, however, many animals in which the colour reflected by the pigment is markedly modified by an overlying layer of complex structure, giving the structural colours such as occur in some blue butterflies and in different iridescent colours. The pigments occurring in animals may belong to one of a number of chemical groups, but those responsible for sexual dimorphic colour characters are usually either melanins or carotenoids, which occur in most animal phyla, or pterins, which supply the wing pigments of many insects. In addition, many sexual colour characters involve the presence of structural colours, one sex being coloured by pigments only and the other by pigments with an overlay of 'structure.' Such structural layers may consist of a medium made turbid by ultramicroscopic spaces giving Tyndall blues, or of a surface-film structure giving iridescent colours of the type seen in a drop of oil spread out on water.

Sexual dimorphism in colour is almost unknown among the less specialized invertebrates, but occurs commonly in the insects. In some of the British blue butterflies ('*Polyommatini*') the difference in colour between the sexes is caused by the presence of structural layers in the wing scales. In the silver-studded blue (*Plebejus argus*) the female is drab brown in colour, being pigmented with melanin, whereas in the bright blue of the male's wings melanin pigmentation is overlaid by structural modifications in the scale surfaces. In transmitted light the wing appears dark brown.

The control of these sex characters in insects is genetic, and there is no evidence that hormonal factors play any part.

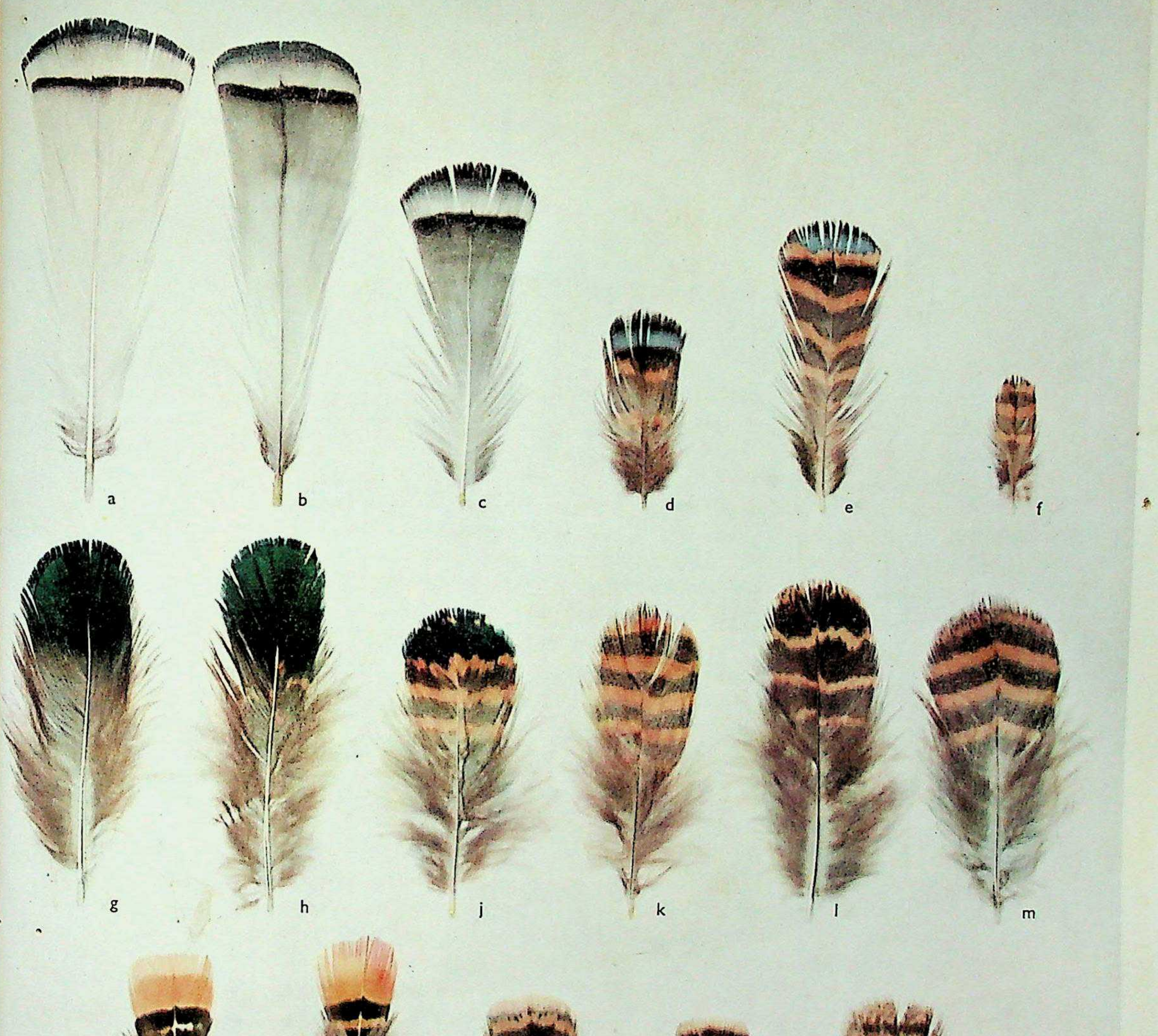
In fishes, sexual dimorphism in colour occurs most frequently among some of the tropical species, many of which are successfully kept and bred by aquarists in Britain. However, some species which are commonly caught along the British coasts show the phenomenon just as well as those from warmer waters. In the cuckoo-wrasse (*Labrus mixtus*), the male is yellow or orange with five or six bands of bright blue stretching backwards from the eye. The fins are yellow with a large blue spot on the dorsal fin. The female is soft red-brown on the back, but lacks the blue bands entirely. It has, however, two black spots on the back near the dorsal fin, and a third similar spot near the tail. The yellow of the male and the red-brown of the female are both carotenoid colours, but no work has been done to show whether they are chemically identical. It is, in fact, possible for two different colours to be produced by the same carotenoid; in such a case it is usual for a red or yellowish colour to be produced by the free carotenoid, and for the other colour, which may be blue or green, to be produced by the same carotenoid linked with a protein radical. The blue of the male cuckoo-wrasse is produced by melanin with an overlay of structure, and the black spots of the female by melanin alone. This fish occurs in many coastal areas of Britain, more particularly in rocky areas. Further out, in the trawling grounds of the English Channel, large numbers of the dragonet (*Callionymus lyra*) are caught. This species shows very striking sexual dimorphism. The painting (plate 2) of the related *Callionymus reticulatus*, a species which has recently been rediscovered in trawl catches off Plymouth, shows the extent of the sexual colour and pattern differences. In the dragonets, the bright coloration of the male becomes fully developed only at the onset of the breeding season, but mature males can always be distinguished from females by some colour differences, as well as by the greater development of the snout and dorsal fin rays.

In birds, sexual differences in colour and other characters are widespread, and many examples can be found among wild and domestic species in Britain. In the common fowl, sexual dimorphism in colour occurs in the comb and wattles as well as in the plumage. The enlarged comb and wattles of a domestic cock are conditioned by the testis secretions, for the small, poorly developed comb of a young male will enlarge if the bird is given injections of a male hormone such as testosterone. On the other hand, the plumage of domestic fowls is modified by the action of ovarian hormones, for it can be shown that the dull plumage of the brown Leghorn hen appears only in the presence of ovarian secretions, and that the plumage of an ovariotomized female (or poulard) is similar to the bright plumage of a normal male, or of a capon. Furthermore, a capon injected with an ovarian hormone throughout a feather-growth period develops a female type of plumage more or less indistinguishable from that of the normal hen.

In the domestic fowl, therefore, sexual dimorphism in the colour and pattern of the feathers is maintained by the action of oestrogens on the developing feather germs. It is, however, not possible to generalize on sexual dimorphic plumage from this one example, because even the members of a related group, namely pheasants, do not behave in exactly the same way. It has been found that, as in the case of the domestic fowls, the dull coloration of the hen pheasant appears only in the presence of ovarian hormones, and, further, that hen pheasants with ovarian deficiencies tend to assume a male type of coloration. Similarly, in a cock or a caponized pheasant injected with an oestrogenic hormone, the feathers growing during the period of the treatment will be female in colour, but they do not assume all the pattern-details of a normal female feather. In particular, there is a difference in the angle which the colour bars make with the shaft. This can be seen in plate 1, in which (m) shows the normal female back feather of an Amherst pheasant, while (k) shows a back feather grown on a male Amherst pheasant receiving daily doses of oestrone. Similar feathers grown in two other feather tracts are also shown in plate 1.

The colours shown by the two barred feathers (plate 1, k and m) are dark brown and light brown, and are produced by different stages of oxidation of melanin. These colours are purely pigmentary, and the reflection from the surface is dull. On the other hand, in the normal male back feather (plate 1, g) and in the dark bars of the male pendent feather (a), the reflection is iridescent, and the main colour is a dark green. Here the pigmentary colour, a melanin deposited in the barbules, is overlaid by a thin film structure. In these iridescent male feathers the barbules are twisted on their own axis and present their broad flat sides to the observer, whereas in the matt female feathers there is no torsion of the barbules, which present their narrow upper edges. This is in itself an interesting sexual dimorphic character, and like the colouring of the back feathers it is controlled by ovarian hormones. As the dose of oestrone increases, the back feathers of a male Amherst pheasant show less and less torsion of the barbules, until with the larger doses (k) the barbule structure is indistinguishable from that of the homologous barbules in a normal female back feather.

In pheasants, therefore, some sexual dimorphic characters, such as barbule torsion, feather colour, and to a certain extent feather size, appear to be controlled by hormonal factors, but other



ATE I – *The effect of varying doses of oestrone on the colour and pattern of feathers from three tracts of the male Amherst Pheasant.* *p row, pendent tract; middle row, back tract; bottom row, saddle tract.* (a), (g), *and* (n) *Normal male feathers;* (b), (h), *and* (o) *thers grown on male receiving* 2·5 γ *oestrone per day;* (c), (j), *and* (p) *feathers grown on male receiving* 10 γ *oestrone per day;* *and* (k) *feathers grown on male receiving* 50 γ *oestrone per day;* (e), (l), *and* (q) *feathers grown on male receiving* 100 γ *oestrone* *day;* (f), (m), *and* (r) *normal female feathers.*

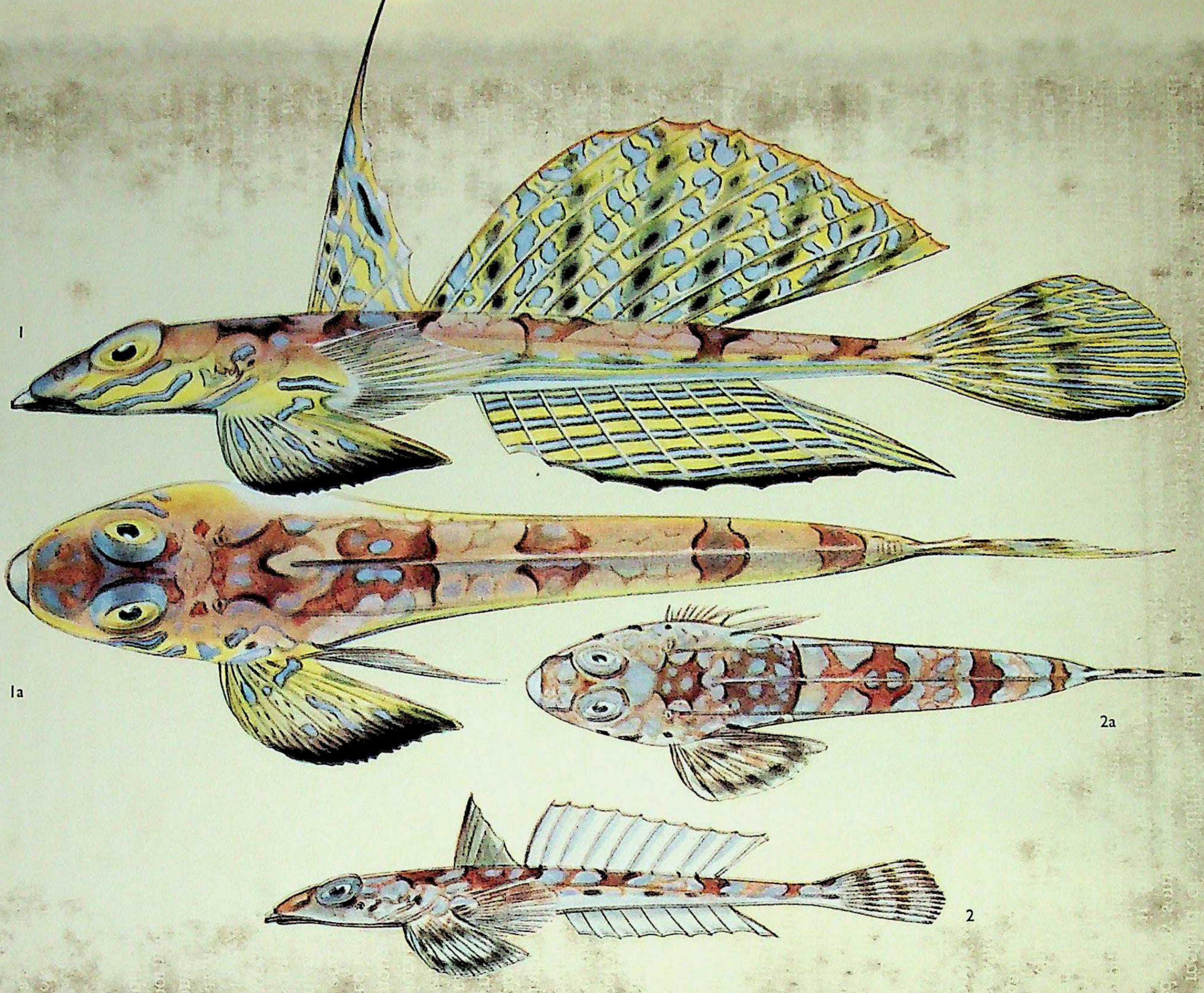


PLATE 2 – Callionymus reticulatus C. & V. *Figures 1 and 1a show in lateral and dorsal view a male, 108 mm in length, which was caught off Plymouth on 11th May, 1950. Figures 2 and 2a show a female. (From an original coloured drawing by A. Fraser Brunner.)*

dimorphic characters, in particular the details of the barring patterns, are independent of the hormones and are probably under genic control. This method of sex differentiation has been referred to by some writers as the pheasant type to distinguish it from the hen type, where sexual dimorphic characters appear to be entirely controlled by hormonal factors. There is, however, among birds yet a third method of sex differentiation, which is usually termed the sparrow type. In many passerine birds it has been found that the sex hormones have no effect on the differentiation of sexual dimorphic plumage types. Thus Crew and Munro [2] have shown that control of the plumage is entirely genetic in the Gouldian finch (*Gouldaeornis gouldiae*), a coloured Australian species with pronounced sexual dimorphism.

The sparrow or insect type of control allows the appearance of clear-cut gynandromorphic animals, in which one side of the body shows male, and the other female, characters. In passerine birds and in insects an abnormal lateral sex-chromosome distribution early in development may lead to one side of the adult being genetically male while the other side is genetically female. This happened in the two Gouldian finch gynandromorphs described by Crew and Munro [2], where there is a clear line of demarcation in the plumage between a male and a female side. Similarly, it is not uncommon to find gynandromorphic insects. Ford [5] has published figures of gynandromorphic butterflies, including one of a particularly striking case in the common blue (*Polyommatus icarus*), in which the left side is female in coloration and the right side male.

Among domestic fowls, birds have been described in which the two sides of the body differ in size, and this lateral asymmetry has been attributed by Crew and Munro [2] to abnormal autosome distributions. These birds, however, are not necessarily sexually abnormal, and it is difficult to see how a true gynandromorph could appear in the fowl. Any bilaterality of sex-chromosomes in the cells of the skin would be masked by hormonal factors, and the whole plumage would be female in the presence of a functioning ovary, and male in its absence. There are, of course, cases where old hens with atrophied ovaries show patches of cock-type feathers. This is because the feather tracts have different thresholds of response to the oestrogenic hormones.

In the intermediate pheasant type of sex differentiation it is conceivable that a bird might appear with some degree of bilateral asymmetry of plumage. If it had an ovary, one side would have normal female feathers and the other would have intersexual feathers—female in colour but not in pattern. If, on the other hand, the bird had no functioning ovary, one side (with female sex-chromosome distribution in the skin cells) would have intersexual feathers—male in colour but not in pattern—and the other (genetically male) side would have normal male feathers. These four types of feathering have been produced experimentally in the common pheasant (Danforth [3]) and in the Amherst pheasant (unpublished data), but the nearest approach to a natural gynandromorph is the common pheasant first described by Bond [1] and re-examined by Huxley and Bond [7].

The development of sexual colour characters is, in fact, but one of the processes involved in sex differentiation. The determination of the primary sex is controlled by the genetic constitution of the individual, that is, by the quantitative supply of sex-chromosomes. If the embryo has only one X chromosome, it will develop in mammals into a male, and in birds and butterflies into a female, while the presence of two X chromosomes will determine the opposite sex. In some animals, such as insects and passerine birds, the sex-chromosomes continue to exert an effect throughout life by controlling the differentiation of sexual dimorphic characters, whether in colour or other attributes. In other groups of animals the sex-chromosomes determine the primary sex of the genital glands, and the secretions of these glands then control the course of future sex-character differentiation. The existence of an intermediate type of sex-character control in the pheasants does, however, suggest that there may be other animals with a similar type of control.

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Chemical identification by a physical method

MARY W. PORTER

For more than a century it has been recognized that the constancy of the interfacial angles of crystals provides a means of identifying them. By 1912, an index of some ten thousand different crystals had been prepared by Fedorov, but his system proved too complex for general use. The development of a simpler system was begun in Britain by T. V. Barker, and since his death in 1931 has been continued at Oxford. The first volume of data for use with this system has just been completed; it is an outstanding event in the history of chemical analysis.

It is well known that many crystals are bounded by plane faces, often with highly reflecting surfaces. The angles between these faces are characteristic of the chemical substance, and as early as 1669 Nicolaus Steno proved 'the constancy of angles' in measuring the angles of cross-sections of quartz. The first measurements of crystal angles were, of course, made by rather crude methods, but early in the last century goniometers were devised expressly for measuring the angles between crystal faces. The first two-circle goniometer was devised by W. H. Miller in 1874. Modern goniometers can measure angles with an accuracy of a few seconds of arc.

Since the angles of many thousands of substances have been accurately measured and recorded in the scientific literature, it would seem that in these measurements the chemist has a means of identifying a large number of substances. Why is it that he has hitherto been unable to make practical use of this apparently simple method of identification? The difficulty lies in the fact that many crystals are rich in faces and therefore have many interfacial angles. For purposes of identification it is obviously essential that, with a given substance, the same angle (or angles) shall always be taken as the classification angle(s). How is it to be decided which shall be chosen? The symmetry of the crystal does not necessarily settle the choice.

A somewhat crude illustration of the difficulty may be seen in figures 4–6. These figures represent the same crystal, acecaffin, drawn in different positions. Three crystallographers in different laboratories may each select a different north-pole position from which to measure and describe this crystal, and a different set of angles will be obtained in each case. If, by chance, all three select the same position, a second difficulty may still remain. The crystal may be rich in faces. Which of these faces shall be treated as the unit face to which the positions of the remaining faces may be referred? Figure 7 shows the terminating faces of a natural topaz crystal; figure 8, in which it is easier to see the problem, shows the same crystal ideally developed. It is necessary to decide which of the faces 7, 8, or 9 shall be accepted as the unit face.

A number of crystallographers have studied the problem of how the unclassifiable crystal measurements existing in the literature could be converted into an index of angles unambiguously applicable to the identification of chemical substances. In 1842 Frankenheim [3] classified 700 substances according to an archaic form of axial ratios; this work remained unnoticed except by T. V. Barker [4]. Later, a remarkable and extensive attack upon this problem was made by E. S. von Fedorov, professor in the School of Mines at St Petersburg (Leningrad). His method, which was based on theories of crystal structure, proved successful. In 1902, crystals of 50 substances, varying in their degree of chemical complexity, were sent to Fedorov from England for identification. Each was in a separate tube, numbered but unnamed. Fedorov measured the crystals and sent back 48 correct identifications. Crystals in the 49th tube were too ill-formed for measurement, and the 50th tube contained a substance which was not in his index, and which had, indeed, never previously been examined crystallographically [5]. The two substances shown in figures 1 and 2 were identified by the Fedorov method.

Barker achieved a notable success with Fedorov's method when he was sent by Dr Govaerts a crystal of unknown composition which had been removed from the intestines of a soldier. This crystal is shown in figure 1; its actual

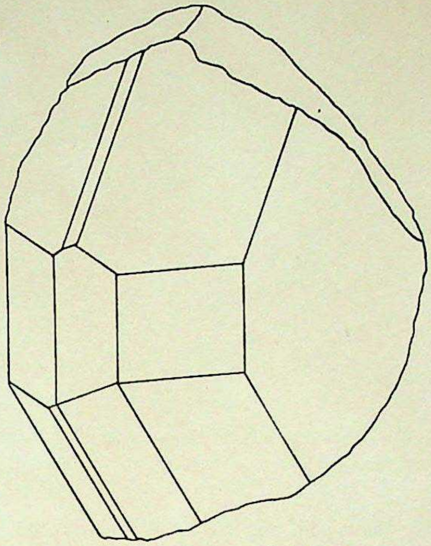

FIGURE 1 – *Salol.*

dimensions are 9 × 7½ × 4·5 mm and its weight 0·229 g. The front of the crystal is well developed, with clearly defined crystal faces; the back is rounded. After an investigation lasting 65 minutes, and without recourse to chemical analysis, Barker identified the substance as the drug salol (phenyl salicylate). A simple confirmation of this diagnosis was made by a melting point determination with a splinter of the crystal weighing less than 100 μg; the optical properties of the resolidified material were examined under the microscope [1].

Figures 2 and 3 show crystals of struvite ($NH_4MgPO_4.6H_2O$), found in the lungs of a dissected subject. These crystals were identified by Barker and the present writer by Fedorov's method [2].

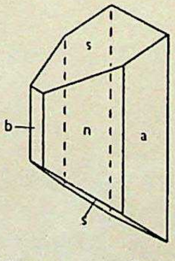

FIGURE 2 – *Struvite.*

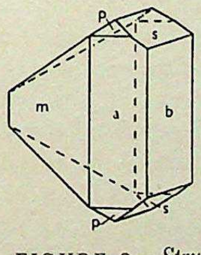

FIGURE 3 – *Struvite.*

The success of these tests made an impression upon crystallographers, particularly upon Sir Henry Miers. At his suggestion, Barker went to Russia in 1908–9 to learn more of Fedorov's method; he returned with the hope of promoting it and making it more widely accessible. Fedorov presented his great crystal index, *Das Krystallreich*, which included some 10,000 substances, to the Russian Academy of Sciences in 1912, but it was not published until after his death in 1920 [6]. Barker collaborated in compiling *Das Krystallreich*, but he gradually became convinced that Fedorov's method, based as it was on theories of crystal structure and involving lengthy and complicated calculations, was too complex for general use. He therefore began to work out a simpler method, based, not on structure, but purely on geometrical form, and necessitating fewer calculations. He succeeded in devising a set of simple rules to be applied in choosing the classification angles for an index, and these were published in a small work, *Systematic Crystallography* [4]. Barker intended that this work should be followed by an index of crystal angles, a project in which he was encouraged by Lord Rutherford and Sir Henry Miers. The date

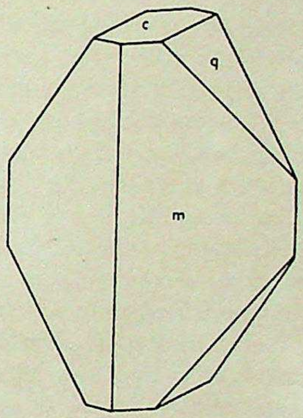

FIGURE 4 – *Acecaffin* (*author's position*).

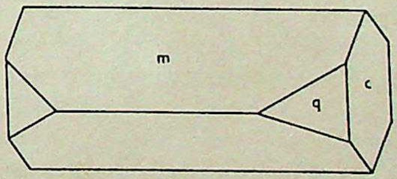

FIGURE 5 – *Acecaffin* (*Barker's position*).

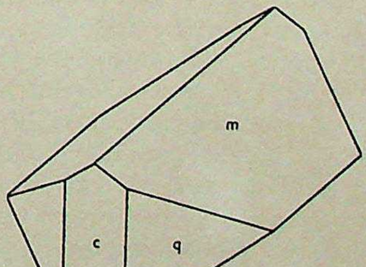

FIGURE 6 – *Acecaffin* (*another position*).

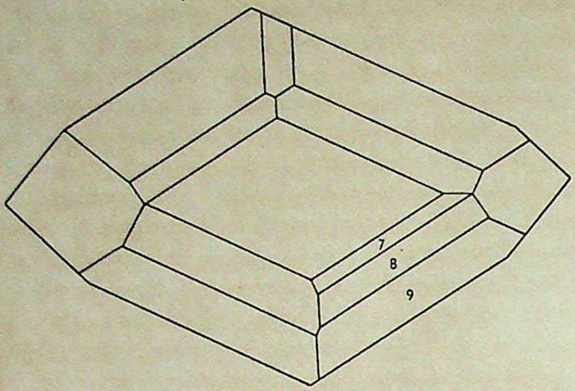

FIGURE 7 – *Topaz. Terminating faces of natural crystal.*

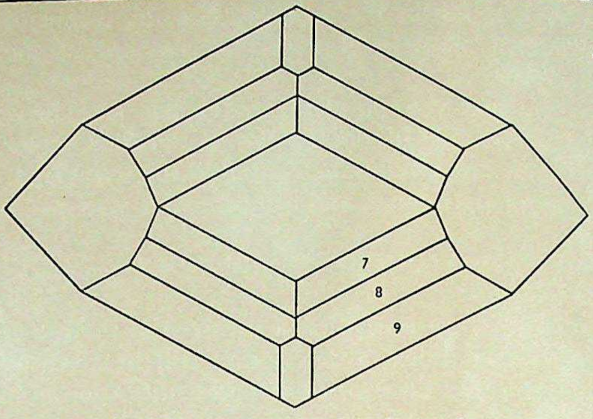

FIGURE 8 – *Topaz. Terminating faces of same crystal ideally developed.*

fixed for the start of work on the index was 1st May, 1931, but Barker died suddenly a fortnight earlier.

The possibility of compiling the Barker index after the death of its originator, and without his direction, was immediately discussed at Oxford by a number of crystallographers, and they decided to test the method independently. At the end of a year, they unanimously concluded that the method was workable, and it was decided to proceed with the preparation of the index.

After some years, the compilation of the index was held to be sufficiently far advanced to offer material for a searching test of its usefulness for the identification of compounds. An earlier test set by the present writer had been successfully carried out by Barker, and was described by him [4], but this was of limited value because Barker was exceptionally familiar with the work and because the number of substances that could then be tested was comparatively small. It was decided to carry out the new test in two of the less simple crystal systems, the orthorhombic and the monoclinic. A list of some 1230 substances which were ready for insertion in the index was sent to Dr G. M. Bennett, Government Chemist (then professor of chemistry at King's College, London), who had offered to collaborate in the test. From the list he selected 16 substances which he sent, numbered but unnamed, to Oxford [7]. Fifteen of the sixteen were successfully identified. It proved impossible to measure the remaining one as the faces were not sufficiently good to give even fair reflections on the goniometer. A list of the substances sent is given below.

It will be seen that many of these substances have a complicated chemical composition, and would be difficult to identify by other means, especially if, as was the case, only one or two small crystals were available for examination. The time taken to identify each compound varied from thirty minutes for the easier crystals to four hours for the most difficult.

List of compounds identified in a test of the Barker index

1. Ethyl-2:4-dinitrophenyl-aniline.
2. Methylanilide of benzene sulphonic acid.
3. Benzene-azo-β-naphthyl benzoate.
4. Tribenzylamine.
5. Phenyl benzoate.
6. 1-Phenyl-3-methyl-4-benzylidene-pyrazolone.
7. Methylanilide of *p*-toluene sulphonic acid.
8. Sodium nitroprusside (dihydrate).
9. Potassium sulphate.
10. Sulphur.
11. (Unmeasurable.)
12. Ammonium sulphate.
13. Eugenol benzoate.
14. Potassium nitrate.
15. Potassium dihydrogen orthophosphate.
16. Topaz.

By means of the index, F. A. Bannister and M. H. Hey were able to identify some crystals found by the Scotia Expedition in oceanic bottom samples from the Weddell Sea [8]. Several of the crystals, which varied in size from 0·2 × 0·1 mm to 0·3 × 0·15 mm, were successfully measured, and the Barker classification angles were determined. The tetragonal symmetry of the crystals was confirmed by their optics and by Laue photographs. From a table of tetragonal substances, compiled by Hey according to Barker's method, the salt was identified as hydrated calcium oxalate.

Identification in the ordinary way, by means of chemical analysis, was in this case out of the question.

The first volume of the index has now been completed [9]. It contains the classification angles of 3000 compounds belonging to the tetragonal, hexagonal, trigonal, and orthorhombic systems.

IDENTIFICATION OF AN UNKNOWN SUBSTANCE

In order to show what is involved in the use of the Barker index, a description will be given of the processes necessary for the identification of a crystal of an unknown substance. The description will be confined to the practical problem, and no account will be taken of the underlying principles. Possible complications will also be ignored, but it should not, on that account, be thought that they cannot be dealt with.

The most convenient type of instrument to use in the identification is a two-circle goniometer; such an instrument was used exclusively by both Fedorov and Barker. Hitherto the Goldschmidt two-circle goniometer has been best known. This apparatus is fitted with a telescope and collimator and two divided circles—the vertical circle (V) and the horizontal circle (H)—at right-angles to one another. The crystal is mounted with a little wax on a holder which fits into a socket on the goniometer head; it is so rotated on the goniometer that each face in turn is brought to the reflection position. Light from the collimator falls on the crystal face and is reflected through the telescope, where the image of the illuminated collimator slit is produced; this image is set as exactly as possible on the cross-wires of the telescope and readings are taken of the position on the two circles. From the V reading is obtained the angle corresponding to geographical longitude; the H reading yields the angle corresponding to the geographical latitude. A two-circle goniometer is now being made in Britain, but if a two-circle instrument is not available, the measurement of the crystal can be made with a one-circle goniometer. This is more laborious both as regards measurement (since the crystal must be remounted after the measurement of each zone) and in the subsequent making of a map or projection.

The first step in identifying a crystal is to make a freehand sketch of it so that its faces may be recognized on the goniometer during measurement. Each face is given a number, which appears in the table of measurements and afterwards in the map, or projection, of the crystal. In making his sketch the observer will note that the faces fall into a few zones, or sets of faces with parallel edges. Next, the crystal is mounted and adjusted on the goniometer, so that the axis of one of the zones is parallel to one of the goniometer axes; the V and H readings are then taken for each face and recorded.

For the sake of clarity, a specific case will now be described, and it will be assumed that the measurements obtained are those recorded in table I. Column 1 gives the number which was assigned to the crystal face in the freehand sketch. Column 2 indicates by a Greek letter the quality, whether good, bad, or indifferent, of the reflection of that particular face. In column 3, the indices of the faces are given; these indicate the relative

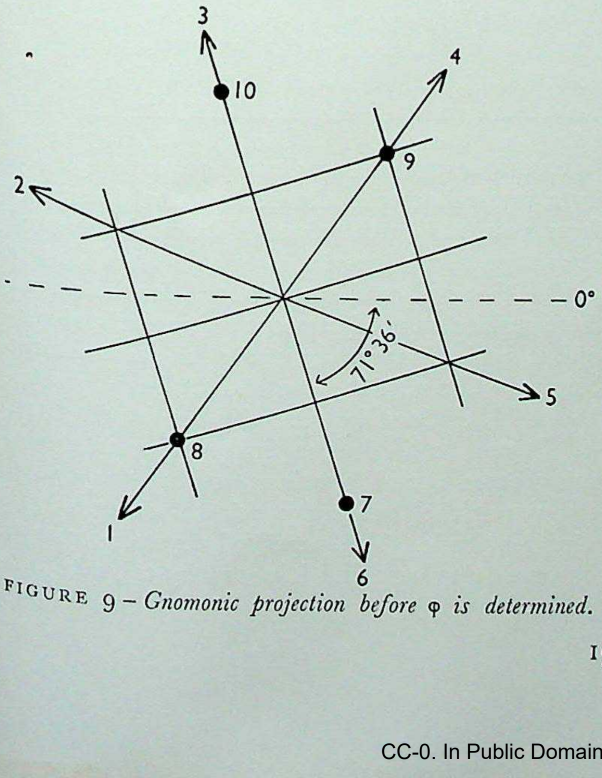

FIGURE 9 – *Gnomonic projection before φ is determined.*

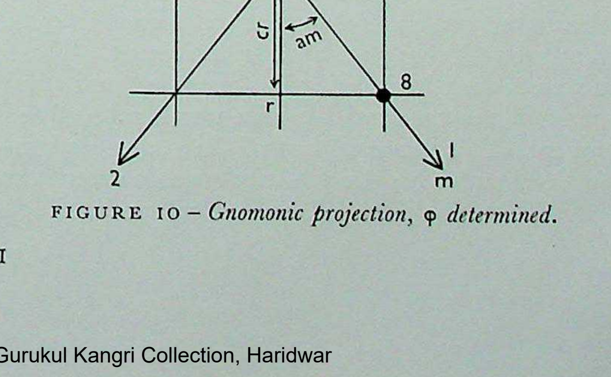

FIGURE 10 – *Gnomonic projection, φ determined.*

TABLE I

1	2	3	4	5	6	7
No. of face	*Reflection*	*Indices*	*V* (*Vertical circle reading*)	φ (= *V* − 71° 36′)	*H* (*Horizontal circle reading*)	ρ (= *H* − 10°)
1	β	m(110)	123° 39′	52° 3′	100° 0′	90° 0′
2	δ	m($1\bar{1}0$)	199° 30′	127° 54′	100° 32′	90° 32′
3	γ	b($0\bar{1}0$)	251° 23′	179° 47′	100° 45′	90° 45′
4	β	m($\bar{1}\bar{1}0$)	304° 2′	232° 26′	99° 55′	89° 55′
5	β	m($\bar{1}10$)	19° 47′	308° 11′	99° 52′	89° 52′
6	δ	b(010)	71° 32′	359° 56′	99° 25′	89° 25′
7	β	k(021)	71° 58′	0° 22′	46° 10′	36° 10′
8	γ	o(111)	124° 27′	52° 51′	41° 4′	31° 4′
10	β	k($0\bar{2}1$)	251° 15′	179° 39′	46° 36′	36° 36′
9	δ[1]	o($\bar{1}\bar{1}1$)	304° 41′	233° 5′	40° 34′	30° 34′

[1] Approximate.

(Dimensions of crystal 2 × 1 × 1 mm.)

TABLE II

System: Orthorhombic Symmetry: 222

Angles: *cr* = 25° 20′, am = 37° 54′, bq = 69° 46′

Forms: m(110), b(010), k(021), o(111)

				Difference		
	cr	am	bq	*cr*	am	bq
1-Naphthylamine-2-sulphonic acid	24° 39′	38° 27′	69° 59′	41′	33′	13′
α-Methyl glucoside	25° 6′	37° 29′	70° 14′	14′	25′	28′
Cinchonine hydriodide methylalcoholate	25° 8′	38° 45′	69° 22′	12′	51′	24′
Diammonium oxalate	25° 22′	37° 57′	69° 42′	2′	3′	4′
Laserpitin	25° 28′	36° 58′	70° 16′	8′	56′	30′
1:8-Dinitronaphthalene	25° 34′	36° 57′	70° 12′	14′	57′	26′
bis-Tripropylammonium platinum hexachloride	25° 47′	37° 13′	69° 52′	27′	41′	6′
Trisodium citrate pentahydrate	25° 55′	38° 51′	68° 37′	35′	57′	1° 9′

inclinations of a face to axes of reference. The readings on the vertical and horizontal circles of the goniometer are given in columns 4 and 6, and from them a projection is made (see figure 9). The two most convenient types of projection are the stereographic and gnomonic; only the latter will be considered here. In the gnomonic projection the crystal is imagined as placed at the centre of a sphere, so that the normal to each face cuts the sphere at a given point. These normals must be imagined as extended until they cut a plane tangential to the north pole of the sphere. This plane is that of the gnomonic projection, and with the two-circle goniometer it is parallel to the plane of the vertical circle. Each face of the crystal is represented on the projection by a small dot, with the exception of the prism faces, which lie in the plane of the projection and are indicated by arrows.

The V and H readings obtained for the several faces require some adjustment before the final gnomonic projection can be made, to allow for the original settings of the two scales. The corrected V and H readings are generally designated φ and ρ. Figure 10 shows the final projection made, using these φ and ρ values, so that the crystal appears in the standard position with an axis at zero longitude. The practised crystallographer, however, does not find it necessary to make two projections.

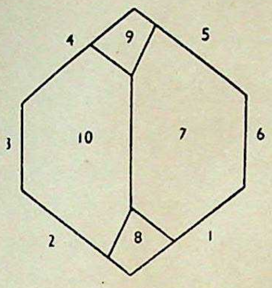

FIGURE 11 – *Orthogonal drawing of ammonium oxalate.*

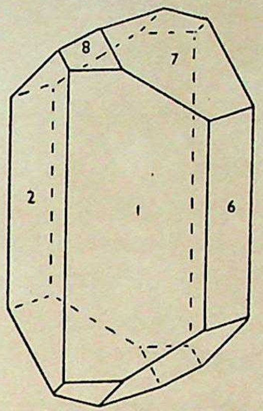

FIGURE 12 – *Perspective drawing of ammonium oxalate.*

The Barker rules are now applied. The most important rule, applicable to all the crystal systems, is contained in the 'principle of simplest indices,' that is to say, the choice of indices involving, if possible, only the integers 0 and 1. Further, as shown in figure 10, there are three classification angles for the orthorhombic system, *cr*, am, bq, and the angle am must be less than 45° and nearer to 45° than *cr* or bq. The main classification angle for orthorhombic compounds is *cr*, and compounds are listed according to this angle. The angles found for the unknown crystal which we are assuming to be under investigation are as follows:

cr = 25° 20′, am = 37° 54′, bq = 69° 46′.

Having obtained these angles, the orthorhombic classification-angle table in the index is consulted; the values of the *cr* angles from 24° 39′ to 25° 55′ are examined to allow for possible variations due to imperfections in the crystal. There are sixty-one entries between these limits, and the second classification angle must now be taken into consideration. The value of the latter cuts the list (see Table II) of possible compounds to eight, and the close agreement in angle between those of the unknown crystal and of diammonium oxalate in the list strikes the eye at once. The next step is to study the form-development of diammonium oxalate in the descriptive part of the index; this is found to be the same as that of the specimen and the identity of the compound as diammonium oxalate is established. Figure 11 is a drawing made looking down from directly above; figure 12 is a perspective drawing. The identification of this particular substance took 1½ hours.

In certain other cases of identification, it may be necessary to consult the descriptive part of the index for any one of the other simple physical properties, such as colour, cleavage, melting-point, density, or optical properties; this course was strongly recommended by Barker for confirming the determination.

It has been shown in some detail that the Barker method can be of practical value to the chemist, and it may be added that it has some peculiar advantages over other methods of identifying chemical substances. For example, the amount of material required is very small, since a crystal measuring no more than half a millimetre in any direction can be classified, and the material is left intact at the end of the measurement. Yet another advantage is that a complex compound can be identified as quickly as a simple one, and in far less time than a chemical analysis would take.

It is a pleasure to record the assistance offered from many quarters in the crisis which followed Dr Barker's untimely death so shortly before work on the index was due to begin. With the kind permission of the late Professor H. L. Bowman, those engaged in compiling the index made their headquarters in the mineralogical department of the University Museum at Oxford. On Professor Bowman's retirement in 1941 these facilities were continued by Mr R. C. Spiller and Mr H. M. Powell. Since 1948, the working headquarters have been in the department of geology and mineralogy, by kind permission of Professor J. A. Douglas and of his successor, Professor L. R. Wager.

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The polyhedral diseases of insects

KENNETH M. SMITH

Although their serious investigation is of very recent date, the viruses which attack insects have already proved to be most interesting. Particularly so is the association between the virus particles themselves and the extremely tiny polyhedral crystals which form within the bodies of infected caterpillars. These crystals, which withstand drying, are extremely efficient carriers of the disease, and attempts have been made to use them for practical ends—for example, in attacking the spruce budworm, which is a serious pest in Canadian forests.

In 1892 a Russian botanist, Iwanowsky, was investigating a disease of the tobacco plant, known as tobacco mosaic, and during his experiments he demonstrated that it was caused by an agent so small that it could pass through the pores of a bacteria-proof filter-candle. This discovery of the filterable viruses opened the door to a kingdom probably as large as that revealed in the seventeenth century by van Leeuwenhoek's discovery of his 'little animals.' The two discoveries are, however, not quite comparable. By means of the microscope—even the primitive instruments of van Leeuwenhoek—it was possible to see and describe bacteria and other inhabitants of the new world of microbiology. No optical microscope can reveal the viruses, because, with very few exceptions, they are beyond the resolving power of microscopes using visible light. The invention of the electron microscope and the development of the ultracentrifuge have, however, transformed the situation, and it is possible with modern techniques to see and to photograph even the smallest viruses.

Viruses attack all kinds of living organisms, from bacteria to man himself. Those which have been most closely studied are, apart from those attacking the higher animals, the plant viruses and the bacterial viruses; the latter used to be called bacteriophages. There is, however, a large group of viruses which attack insects, and these, for some reason, have not received much attention until very recent times. This is rather curious, because many of them are of very great interest, particularly as regards the extraordinary changes which take place inside the body of the infected insect. The resulting diseases are called polyhedral diseases because of the development in the body of the insect of huge numbers of many-sided crystals, some of which can be seen in figures 2, 4, and 10.

TYPES OF INSECTS ATTACKED BY VIRUSES

Virus diseases of the polyhedral type have been recorded from various kinds of insects, but mainly from those belonging to the *Hymenoptera* (ants, bees, and wasps) and the *Lepidoptera* (butterflies and moths). By far the greater number has been recorded from the *Lepidoptera*, though no doubt with further study other groups will be found to be susceptible. An interesting feature about polyhedral insect viruses is that they attack only the larval stages, the adult insects apparently being immune.

Several of these virus diseases affecting caterpillars have been known for a number of years; they must, however, represent only a fraction of the viruses which exist. Indeed, experience at Cambridge has shown that if caterpillars are bred on a large scale for some time, a virus disease always appears eventually. This has proved to be so with five species of tiger-moth larvae, four species of the so-called giant tropical silk-moths (figure 1), and the currant-moth (*Abraxas grossulariata*). None of these viruses had been previously described. A possible explanation of the sudden appearance of a virus in a group of apparently healthy caterpillars will be discussed later.

Two of the best-known polyhedral diseases of caterpillars are those attacking the silkworm (*Bombyx mori*) and the nun-moth (*Lymantria monacha*). The first of these diseases is usually known as 'jaundice', because of the yellow colour assumed by the infected silkworms. The Germans gave the second the peculiar name of *Wipfelkrankheit*, or tree-top disease. This was because towards the end of the last century a tremendous epidemic broke out among the great populations of nun-moth larvae which were destroying much of the spruce forests of central Europe. The infected caterpillars tended to migrate to the tops of the trees, where they died but remained hanging, attached by their abdominal feet. Such dead caterpillars are merely limp sacks half-full of polyhedral bodies. It has been suggested that this wholesale migration to the tree-tops might be connected with partial suffocation due to the pressure of the polyhedral bodies on the fine tracheal breathing tubes. On this assumption the caterpillars make for the tops of the trees, where there are more air currents. The rapid disintegration of the internal tissues is typical of the effects of these caterpillar viruses. In figure 9 may be seen a dead caterpillar of a foreign silk-moth (*A. io*) hanging characteristically by its abdominal feet.

HOW THE POLYHEDRAL VIRUSES SPREAD

It is certain that the caterpillar viruses are very highly infectious. The polyhedral bodies are not the virus particles themselves, as was thought at one time, but they do contain virus. They are extremely stable, and can be dried and still retain infective virus within them. When they enter the gut of a susceptible caterpillar, they are dissolved by the action of the alkaline secretions, and the virus particles are liberated. The polyhedra act, so to speak, as an extremely efficient kind of parcel-post for the distribution of the disease. One method, therefore, by which caterpillars can become infected is by ingesting the polyhedra while eating leaves contaminated by infected caterpillars. The efficiency of this method of distribution seems, however, to vary with the species of caterpillar, and hence also with the virus, since they are extremely specific in their action. Thus it is easy to infect the larva of the currant-moth by moistening the mouth-parts with a suspension of polyhedra, but less easy to infect some other species in the same manner.

The contamination of the food materials and surroundings by polyhedra is ensured by the symptoms induced by the disease. In some species the infected caterpillar excretes large quantities of fluid containing polyhedra (see figures 6 and 10); the faeces also are infectious. In the last stages of the disease the caterpillar is, as already pointed out, converted into a mere sack filled with polyhedral bodies. The skins of such caterpillars rupture very easily, liberating millions of polyhedra, which, being able to withstand drying, spread infection far and wide. Another and very important method of propagation of polyhedral diseases is by the passage of the virus from parent to offspring; this is a phenomenon which is comparatively rare in the virus diseases of plants and the higher animals.

A description of a polyhedral disease as it occurs in the larvae of the oak silk-moth (*Telea polyphemus*, figure 1) will serve to illustrate some of these points. When a half-grown caterpillar of this species is artificially infected with its specific polyhedral virus, either by ingestion or inoculation, the insect becomes sluggish and ceases to grow, although it may for a time continue to feed. Frequently drops of fluid, at first colourless but later turning black, exude from the body of the animal (figure 6). If such drops are examined under the oil-immersion lens of the optical microscope they will be found to contain large numbers of polyhedral bodies (figure 10). It occasionally happens that larvae becoming infected when nearing maturity complete their larval life, make their cocoon, and may even pupate. If, under these conditions, the cocoon is cut open the dead larva or pupa is found full of polyhedral bodies (figure 7). These remarks apply to the caterpillar which is actively diseased. Sometimes, however, it seems clear that the virus may be present in a latent condition within the caterpillar. The evidence for this is as follows. Apparently healthy caterpillars of the oak silk-moth pupated and gave rise to adult moths. From these moths a number of fertile eggs were obtained. Of the caterpillars arising from these eggs a percentage died of polyhedral disease, the age of the caterpillars varying from fourteen days to less than forty-eight hours. Examination of the caterpillars which died within forty-eight hours of emerging from the egg showed that they contained large numbers of polyhedral bodies. This is interesting, because it indicates that the virus must have been inside the developing larva within the egg, and not merely outside on the shell. It is hardly feasible that so many polyhedra would have developed within forty-eight hours if infection had been derived from the outside of the egg at the moment of emergence of the young larva.

Similarly, some hundreds of larvae of the garden tiger-moth (*Arctia caja*) were bred in the laboratory in a room where no tiger-moth larvae had ever previously been kept. The caterpillars, which were perfectly healthy, were bred continuously through four generations without going through a diapause (resting period). In the fifth generation, a polyhedral disease developed and wiped out the entire stock of caterpillars. It seems clear, therefore, that these polyhedral viruses must be capable of lying latent within the body of a susceptible caterpillar, being passed from one generation to another until, under some stimulus, the nature of which is at present unknown, the virus begins active multiplication and gives rise to the disease. It is possible that careful examination of the tissues of apparently normal caterpillars by means of the electron microscope may yield further knowledge of these latent infections.

The claim has been made on more than one occasion that it is possible to produce virus in silkworms *de novo* by feeding the caterpillars on certain chemicals, and it seems true enough that under some circumstances silkworms, when fed on various chemicals, develop a polyhedral disease. Yet a more likely explanation seems to be that the virus is already present in the animal in a latent or quiescent form, and that the chemical acts as the trigger which sets the virus multiplying and thus causes the disease to develop.

CHANGES TAKING PLACE INSIDE THE DISEASED CATERPILLARS

The polyhedral diseases of insects are sometimes referred to as nuclear diseases because the pathological changes seem to start inside the cell nucleus. Whether all polyhedral diseases begin to develop inside the cell nucleus is not certain; perhaps in some cases the focus of multiplication is in the cell cytoplasm. At all events there is no question but that at some stage in the polyhedral disease these curious many-sided crystals begin to form inside the nuclei of susceptible cells. In figure 2 is shown a photomicrograph, taken with the optical microscope, of a section through a caterpillar of the currant-moth infected with a polyhedral virus disease. The apparent honeycomb structure of the enormously enlarged nuclei is due to the fact that they are packed with polyhedral bodies. A similar state of affairs is illustrated in figure 4, which shows a single cell nucleus from the larva of the common clothes-moth (*Tineola bisselliella*) infected with a polyhedral disease. Judging by the expansion caused by the pressure of the polyhedral bodies contained within it, the nuclear membrane must be extremely elastic. However, the nucleus eventually bursts, liberating the crystals into the surrounding cytoplasm. As the disease progresses, the cells disintegrate, until the caterpillar assumes the condition shown in figure 9.

THE NATURE OF THE POLYHEDRAL BODIES

The relationship between the polyhedral bodies and the virus itself has long been sought. For a time they were thought to be some kind of organism causing the disease, and were given names like *Crystalloplasma polyedricum* and *Chlamydozoon prowazeki*. It was not until quite recently, however, that it was shown that these bodies, which appear to be genuine crystals, are not themselves the infective agents but contain some virus inside them [1, 2].

If a polyhedral body is dissolved in weak sodium carbonate solution and the process followed under the high power of the optical microscope, using dark-ground illumination, an interesting phenomenon can be observed. Each polyhedral body is enveloped in a kind of skin or membrane, and, as the substance of the crystal dissolves, numbers of highly refractive dots can be seen vibrating violently inside the membrane; occasionally one or two pass right out of the membrane and disappear. These dots are the virus particles themselves, which are too small to be resolved by the optical microscope and so appear in the dark field as bright points of light driven about inside the enclosing membrane by Brownian movement.

A much clearer picture of what happens when the polyhedral body is dissolved can be obtained by means of the electron miscroscope, using a magnification of about ten thousand. Figure 5 is an electron micrograph, taken by Dr R. W. G. Wyckoff; it shows, collapsed, the membrane which enclosed the polyhedral body before it was dissolved in weak alkali. The rod-shaped virus particles which have been liberated can be clearly seen. This particular polyhedral body came from an infected caterpillar of the scarlet tiger-moth (*Panaxia dominula*), and well-defined virus rods are always present in this disease. Although many of the polyhedral viruses of insects seem to consist of rod-shaped particles [1, 2], it does not follow that all viruses of this type are rod-shaped. Indeed, there is good evidence that some of the polyhedral viruses are spherical [3], while in other polyhedral diseases no virus particles have as yet been seen.

It will be realized from this brief description of the polyhedral bodies that there is still much to be learnt about their function. We know that they are protein crystals, but of a protein different from that of the virus particles themselves, and that they contain, in some diseases, about 3–5 per cent. of virus. But what is the purpose of the crystals, and why is each crystal enclosed in a membrane? Again, how do the virus particles get into the crystal? Are they occluded during the growth of the crystal, or do they actually form inside it? At the moment we have no answers to these questions, but it seems unlikely that any growth

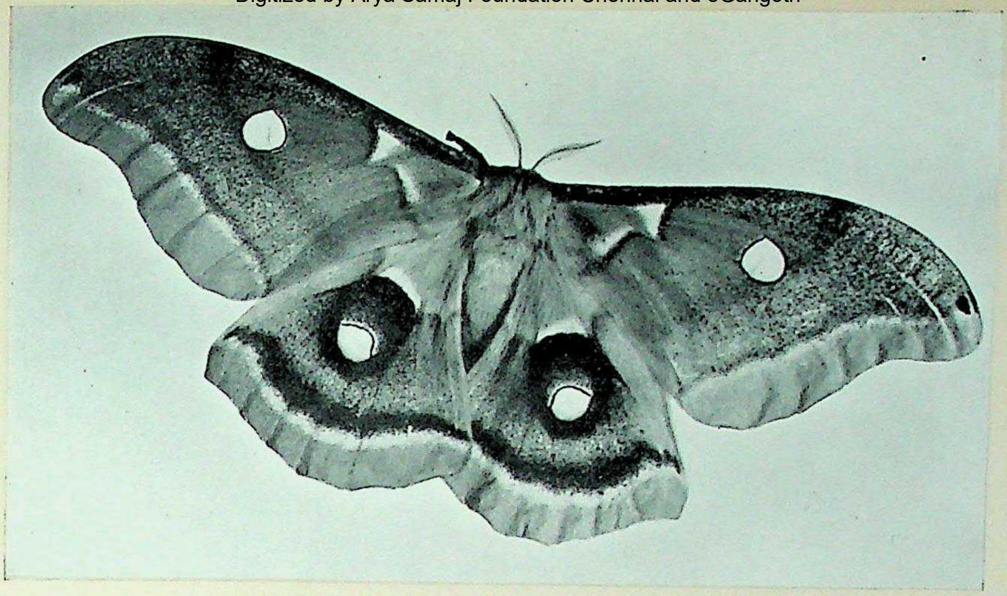
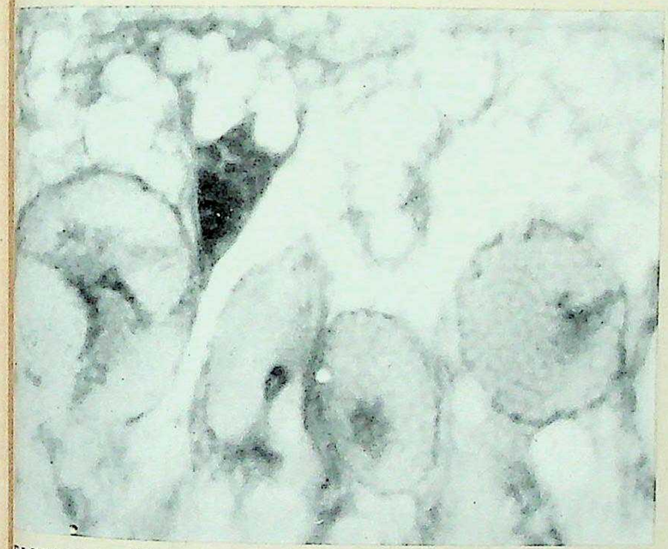


FIGURE 1 – *Female oak silk-moth* (T. polyphemus). (*Slightly reduced.*)



IGURE 2 – *Transverse section through a caterpillar of the currant-moth* (Abraxas grossulariata) *infected with polyhedral disease. Note the cell nuclei packed with polyhedra and enormously distended.* (× *c.* 1200)

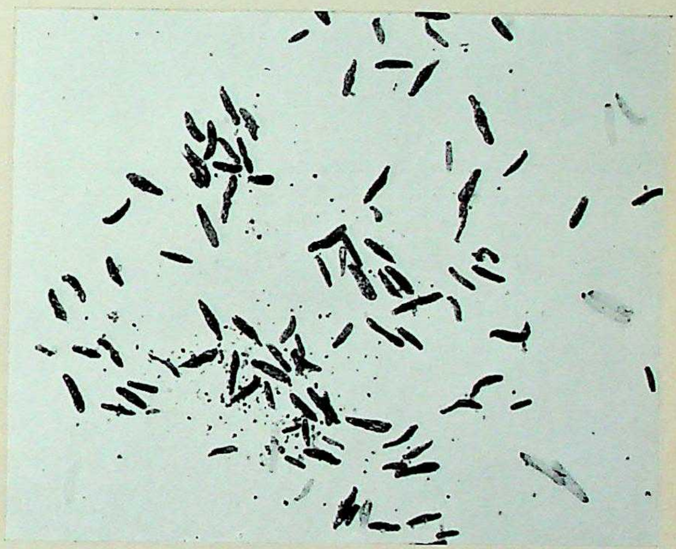
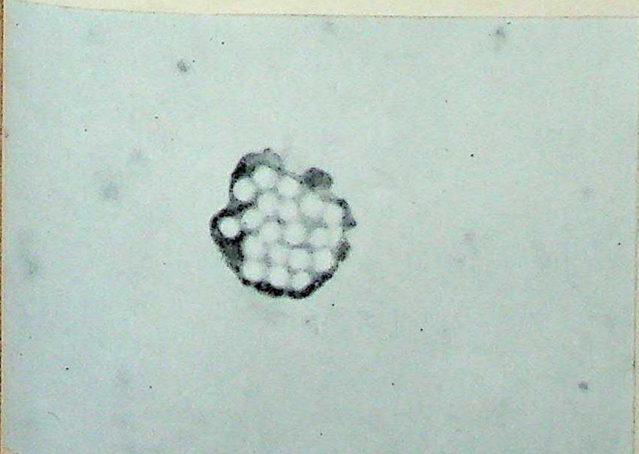


FIGURE 3 – *Caterpillars of the common clothes-moth* (T. bisselliella) *killed by a polyhedral disease. A few normal larvae, pale in colour, can be seen.*



IGURE 4 – *A cell nucleus from one of the dead larvae seen in igure 3. Note the polyhedral bodies.* (× *c.* 1500)

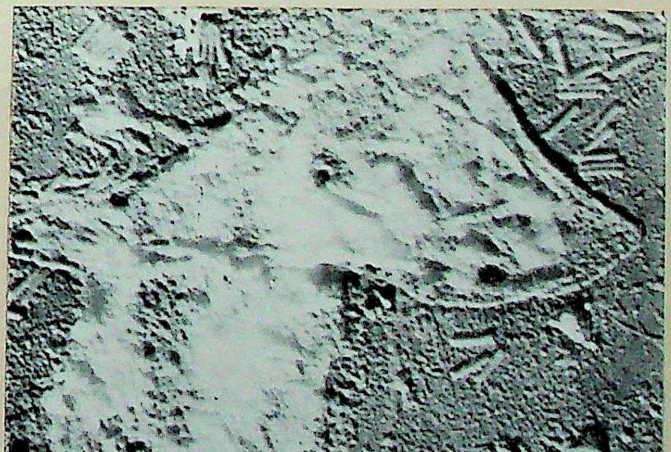


FIGURE 5 – *A single polyhedral body from the caterpillar of the scarlet tiger-moth* (Panaxia dominula). *The crystal has been dissolved in weak alkali, leaving the enclosing membrane and liberating the virus rods.* (× 10,500)

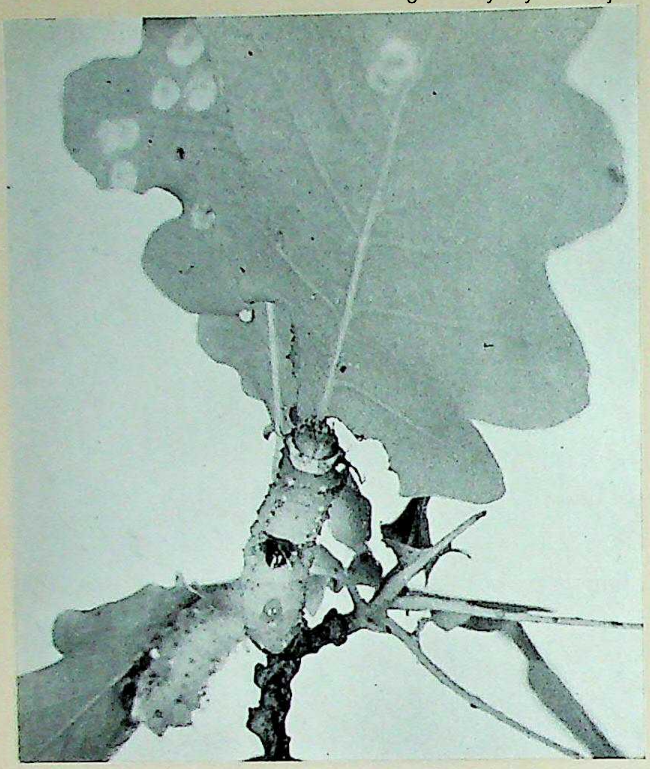


FIGURE 6 – *Two caterpillars of the oak silk-moth infected with a polyhedral virus disease. Note fluid oozing from the dorsal surface of caterpillar in centre.* (*Slightly reduced.*)

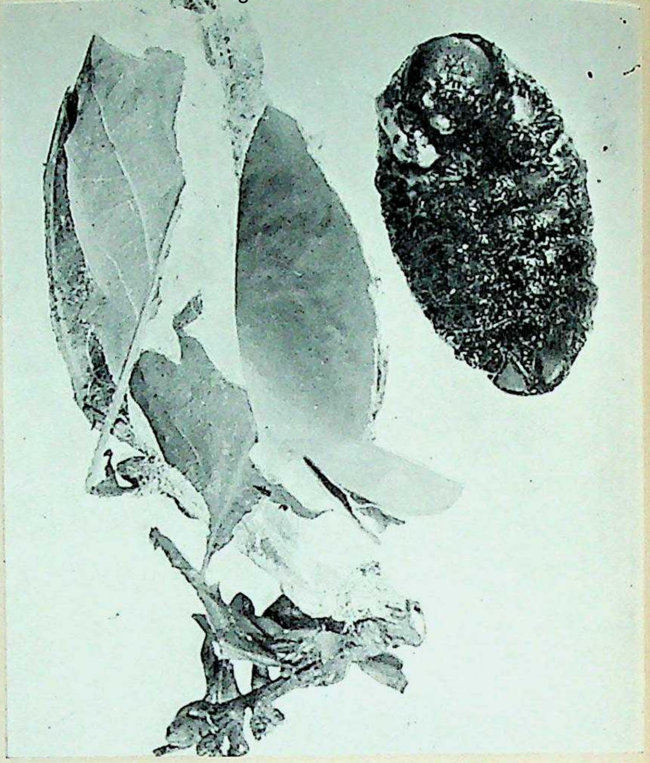


FIGURE 7 – *Infected caterpillar of the oak silk-moth which has failed to pupate; cocoon opened to show dead larva full of polyhedral bodies.*

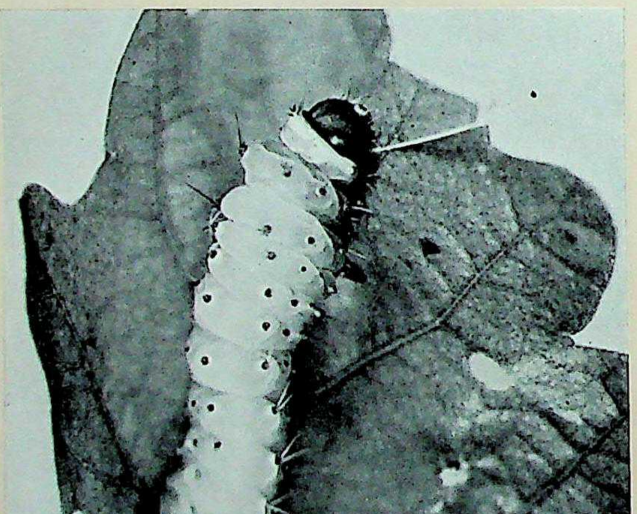


FIGURE 8 – *Healthy caterpillar of the oak silk-moth.* (*Slightly enlarged.*)

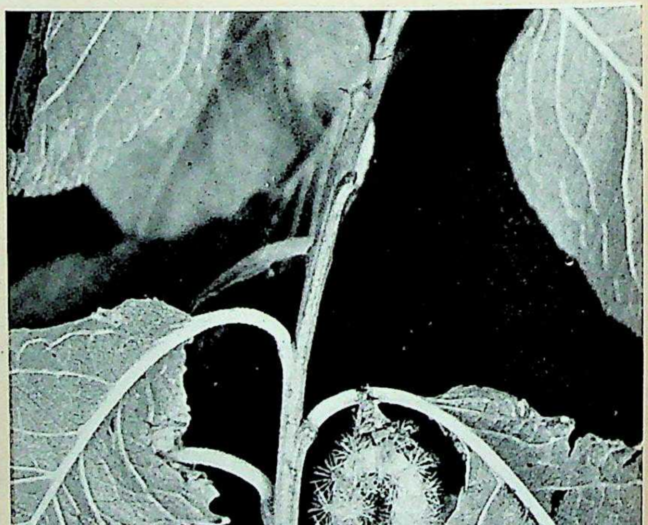


FIGURE 9 – *A caterpillar of the bull's eye moth* (A. io) *dead from polyhedral disease. Note the characteristic appearance of the dead larva—a sack full of polyhedra, hanging by one of the abdominal feet.*

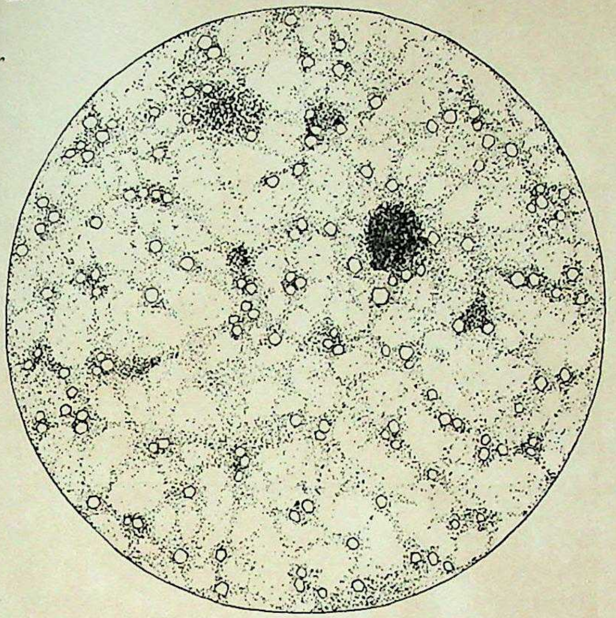


FIGURE 10 – *Fluid from the infected caterpillar shown in figure* 6 *seen under the microscope. Note the large numbers of crystal-like polyhedral bodies.* (× *c.* 750)

could take place inside the actual crystal. Nor does it seem possible that such large numbers of virus rods as occur in some instances could be accidentally occluded during crystal formation. It may be that the formation of the polyhedra is a process analogous to the formation of a pearl in the oyster, and that the crystal is formed in response to the stimulation of the virus rods. It should be realized, however, that polyhedral bodies frequently occur which do not contain any virus rods, even in those diseases where rods are present.

In a study by Dr Wyckoff and the present writer it has proved impossible to demonstrate the presence of any virus in the polyhedra of some diseases. This is true, for example, of the disease attacking the common clothes-moth (*Tineola bisselliella*). Yet the polyhedra are intensely infectious and the larvae are killed by ingesting them with their food (figure 3). It may be, of course, that a new technique is necessary to demonstrate the presence of some of these viruses, but it does not seem to be a question of the virus particles being missed in the electron microscope by reason of their small size.

POSSIBLE USE OF VIRUS DISEASES TO CONTROL INSECT PESTS

We have already mentioned the occurrence of a great epidemic of polyhedral disease among the nun-moth caterpillars in central Europe. Such naturally occurring epidemics have suggested the possibility of stimulating similar virus epidemics among other insect pests by artificial means. Several attempts on these lines are being made at the present time. In Canada, where the spruce budworm is a serious threat to the spruce forests, a virus has been obtained which attacks this insect, and a scheme is afoot to use it to keep down the numbers of the pest.

In California [4] some experiments have already been made, using a polyhedral virus against the caterpillars of the alfalfa (lucerne) butterfly. Huge quantities of infective polyhedra were obtained, either by breeding very numerous caterpillars and infecting them with the virus, or by collecting in the field large numbers of caterpillars already infected. It was found that application of a virus suspension containing 5 million polyhedra per ml at the rate of 23 litres per acre was adequate to ensure infection of a field population of larvae, and to reduce its numbers below an economically serious level, at least under the conditions then obtaining in the northern San Joaquin valley. Application by means of a small aeroplane was found to be the most convenient method of treating large fields with a virus suspension. Ground equipment would be more suitable for application to small fields.

Figure 3 shows the result of disseminating polyhedral bodies among a culture of the caterpillars of the clothes-moth. This virus is very efficacious in destroying the larvae of the clothes-moth in small enclosed spaces such as trunks, wardrobes, chests-of-drawers, or cupboards, but its efficiency on a large scale has not yet been properly tested. Much work remains to be done on the factors governing the spread of the disease on a large scale.

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A link with Captain Cook and H.M.S. *Endeavour*

H. ALAN LLOYD

In the past, the difficulties of navigation and of making exact astronomical observations were very largely due to the lack of exact and reliable chronometers. This article shows that less than two centuries ago several major scientific observations in various parts of the world were—surprisingly enough—dependent upon the use of one particular clock. This clock, made for the Royal Society by John Shelton, travelled between London and places as far afield as St Helena, Barbados, Pennsylvania, and the Arctic, surviving among many other vicissitudes the hazards of shipwreck. Today it is still an excellent timekeeper.

In appraising the efforts of former generations of scientists one is apt to forget the limitations placed on them in the execution of their work by their limited apparatus and equipment. Thus, today, it is perhaps difficult to realize that when the *Endeavour* sailed in 1768, carrying a party of scientific workers to observe the transit of Venus in the South Pacific, the best timekeeping instrument available was a long-case clock with a pendulum of approximately 39 inches, beating seconds. The chronometer, as we know it today, was just being born; at that date there was in existence only one spring-driven timepiece sufficiently accurate to determine longitude at sea. This was John Harrison's No. 4, which had been tested on two voyages, one to Jamaica in 1761 and the other to Barbados in 1764. It was on Cook's second voyage in 1776 that he carried, in the *Resolution*, Larcum Kendall's copy of Harrison's No. 4, which won from him such praise. Larcum Kendall also made the chronometer carried by Bligh in the *Bounty*.

Thus it came about that for the voyage of 1768, Cook had still to rely on dead-reckoning to determine his longitude. When the expedition landed, a long-case clock with a gridiron pendulum was the most reliable timekeeper available. The gridiron pendulum also was an invention of John Harrison; he used it first in his No. 1, which was tested in 1735. The clock used by Cook was one by John Shelton and was lent by the Royal Society, which organized the expedition; it is still in the Society's possession and is in continuous use in the room of one of the officers.

The history of this clock began at a meeting of the council of the Royal Society held on 2nd July, 1760. Preparations were then being made for sending two expeditions to observe the transit of Venus across the Sun's disk on 5th June, 1761. This was the first such transit to occur since 4th December, 1639, when Jeremiah Horrox had succeeded for the first time in observing this rare occurrence. A considerable number of expeditions were then being organized by governments and academies for observations of the transit, with a view to an improved determination of the Sun's distance. It was resolved to buy for £20 'a clock with a pendulum adjusted so as to obviate the variable effects of heat and cold for the observations at the Island of St Helena.' On 14th July Nevil Maskelyne, the Astronomer Royal, was chosen to lead the expedition, with Charles Mason as his assistant; at this meeting it was resolved 'to add £10.10.0 to the price of the clock for a more complete timepiece.'

At about the same time, a second clock was ordered from Mr John Ellicott, F.R.S., a noted clockmaker. Ellicott's clock has nothing to do with the journey of the *Endeavour*, but is mentioned here because, as two expeditions were being fitted out at the same time, the statement that Ellicott's clock was sent on one of them leaves the inference that the Shelton clock was sent on the other.

On 27th December, 1760, Maskelyne and Waddington signed for, and promised to return to the Royal Society, *inter alia* . . . 'a clock with a gridiron pendulum.' On the same day Charles Mason, who had now been appointed to lead a similar expedition to Bencoolen, and Jeremiah Dixon, his assistant, signed for 'a clock by Mr Ellicott.'

On his return from St Helena, Maskelyne, writing on 12th January, 1762, refers to the various experiments that had already been carried out by others to determine the force of gravity in different parts of the earth by measuring the length of the seconds pendulum, and states that he took the opportunity of making similar observations on the occasion of his visit to St Helena; 'the Royal Society furnished me with an excellent clock, with a gridiron pendulum adapted to it, executed by that diligent and ingenious artist, Mr John Shelton.

'Soon after my arrival at St Helena, I set up the clock in the valley near St James' Fort. . . . The pendulum had not been taken off the clock, for carriage, but was secured to the clock case, in order to prevent it from receiving any damage. A piece of wood was secured to the back of the clock case, having a round cavity in it before, just large enough to receive the bob of the pendulum; another piece of wood, with such another cavity in it, likewise fitting the bob of the pendulum, was applied to it, on the forepart, and secured firmly to the other piece, and to the back of the clock case. Two little pieces of wood likewise kept the upper part of the pendulum in its place, from receiving any motion near the centre of suspension.

'When the pieces of wood were taken away and the pendulum thereby disengaged, the clock was fit for use: only to adjust the pendulum to the same exact length, as it was set at Greenwich, a mark had been made on the rod, where the top of the pendulum rose to; and Dr Bradley informed me of the number, which stood against the index, on the nut at the bottom of the pendulum, by screwing or unscrewing which, the bob is elevated or depressed.'

The holes in the back of the case where the clamps were fixed to the bob of the pendulum and at the base of the gridiron can be clearly seen in figure 2. The marks made on the pendulum rod before it left Greenwich are seen in figure 3.

In his report read to the Royal Society on 20th December, 1764, and 20th January, 1765, on his observations in St Helena in 1761, Maskelyne notes 'On October 28th, I took down the clock, packed it up, and sent it aboard a vessel going to the Cape of Good Hope, to return again soon, committing it to the care of Mr Jeremiah Dixon, who had observed the transit of Venus over the sun at the Cape.' (The expedition to Bencoolen, incidentally, did not materialize, for political reasons.) 'He took his passage on board the same vessel, in order to set the clock up at the Cape of Good Hope; and examine the difference of the proportion of the force of gravity, at those two places.' Mason appears to have joined Maskelyne at St Helena, as Maskelyne writes further, 'the same day Mr Mason fixed up his clock for my use. . . . This clock was made by Mr John Ellicott, F.R.S.

'I still continued, for some time, to make observations in the upper room, as before. For this I fixed up a little clock there, which may be called a journeyman clock, having a pendulum swinging seconds, which, after being well adjusted, would keep time regularly for several hours. It had only minute and seconds hands, and struck every minute exactly as the second hand came to sixty, which was very convenient for counting seconds; . . . The little clock, as well as the larger clock which I sent with Mr Dixon to the Cape of Good Hope, was made by Mr John Shelton.'

On 19th November, 1761, Waddington reports from St Helena. On the same date it is 'ordered that £35.8.0 be paid to Mr Ellicott for his regulator.' It is also 'advised that the Society's observers have gone on to the Cape of Good Hope.' On 13th May, 27th May, and 17th June, 1762, are recorded the return of the instruments from the Cape and St Helena.

In 1763 Shelton's clock is again in demand, the Society's minutes of 18th August recording that a letter had been received from Maskelyne requesting the loan of Mr Shelton's clock made for the Society. This was required for use in Barbados, whither Harrison's No. 4 was being sent on its second test in connection with his claim for the £20,000 reward offered in 1714 for solving the problem of accurate measurement of longitude. This sum was to be paid 'to anyone who should invent a practicable method of determining the longitude within ½°.'

Harrison's No. 4 had already made one journey to Jamaica, in 1761, when, after allowing for its rate of going, it was found to be 5 seconds slow, corresponding to an error of longitude of only 1¼ min. On 14th February, 1764, H.M.S. *Tartar* sailed from the Nore with Shelton's clock aboard. On this trip the error of Harrison's chronometer was only 38·4 sec in seven weeks, equal to 9·6 miles of longitude at the Equator.

On 17th October, 1765, a letter was addressed to the Society by Mason and Dixon, proposing to measure a degree of latitude and a degree of longitude in the neighbourhood of Pennsylvania. To this the Society agreed, and on 8th November, 1765, Maskelyne wrote to them to say 'As I do not find that you have a clock with you, I shall make a proposal to the Council of the Royal Society, that their clock, which I took to St Helena and the Barbadoes, may be sent you. . . . Always fix the Clock up firm and adjust the

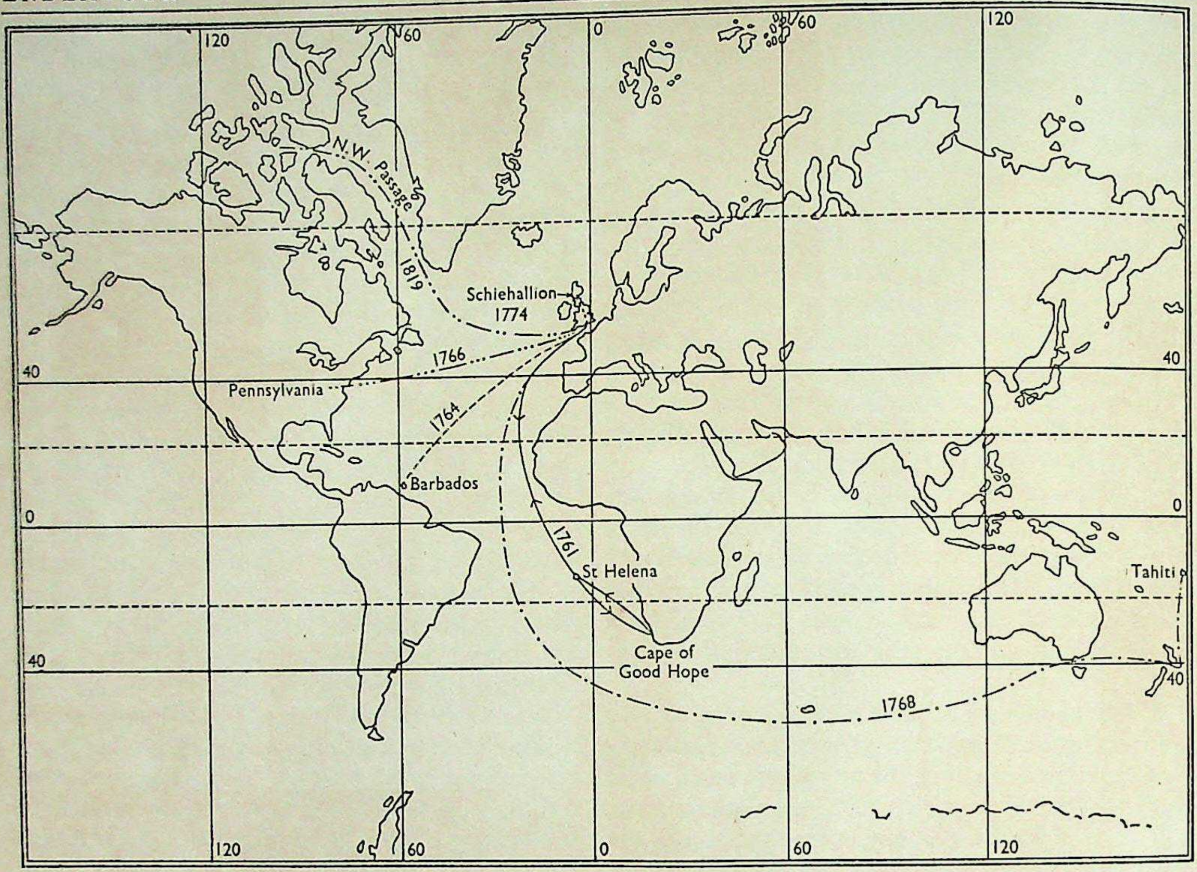


FIGURE 1 – *The journeys of John Shelton's clock*, 1761–1819. [*Diagrammatic.*] *The clock was used only on land.*

pendulum to the same length, and it will keep the same rate of going very nearly. . . .

'Should the Clock be sent you, adjust the pendulum to the Upper Scratch, No. 3 standing against the Index, which answered to sidereal time in St Helena, and keep the clock going for some days, in order to determine its rate of going. . . .'

On 14th November, 1765, Mason and Dixon were advised that the clock, together with other supplies, had been embarked on the *Ellis*, commanded by Samuel Richardson Egdon. This ship sailed in December of that year.

It would appear that the ship was wrecked, for the minutes of August 1766 record the 'supposed wreck of the ship *Ellis*, wherein were the Instruments sent to Messrs Mason and Dixon.' On 15th January, 1767, the Council ordered 'that a letter be sent Messrs Mason and Dixon . . . desiring the return of the clock that had been damaged without Delay.'

The damage to the clock appears to have been confined to a broken suspension spring. Mason and Dixon carried on with it after effecting repairs. Mason writes in his journal: '1766, December 11. The Sector was set up at Mr Harlands. . . . Here we also set up the Clock sent us by the Royal Society of London.' '1766. December 15. This day we set the pendulum of the Royal Society's Clock to the upper Scratch with Number 3 at the Index; as desired by Mr Maskelyne.' Mason and Dixon finished their work by 25th February, 1767, and the clock was taken down and packed in its case on 28th February.

In the meantime, the Society, fearing that the clock had sustained severe damage in the shipwreck, sent a letter of recall on 1st January, 1767, in order to put it right for the observation of the transit of Venus on 3rd June, 1769. This was received by Mason on 24th May, and the clock was carried by four men to Wilmington, and thence by water to Philadelphia. On 19th November, 1767, Maskelyne reported the clock safely back and going at Greenwich.

The transits of Venus occur in pairs with an interval of eight years, the intervals between the pairs being alternately 121½ years and 105½ years. In 1768 arrangements were in hand for expeditions to be sent to observe the transit of 1769.

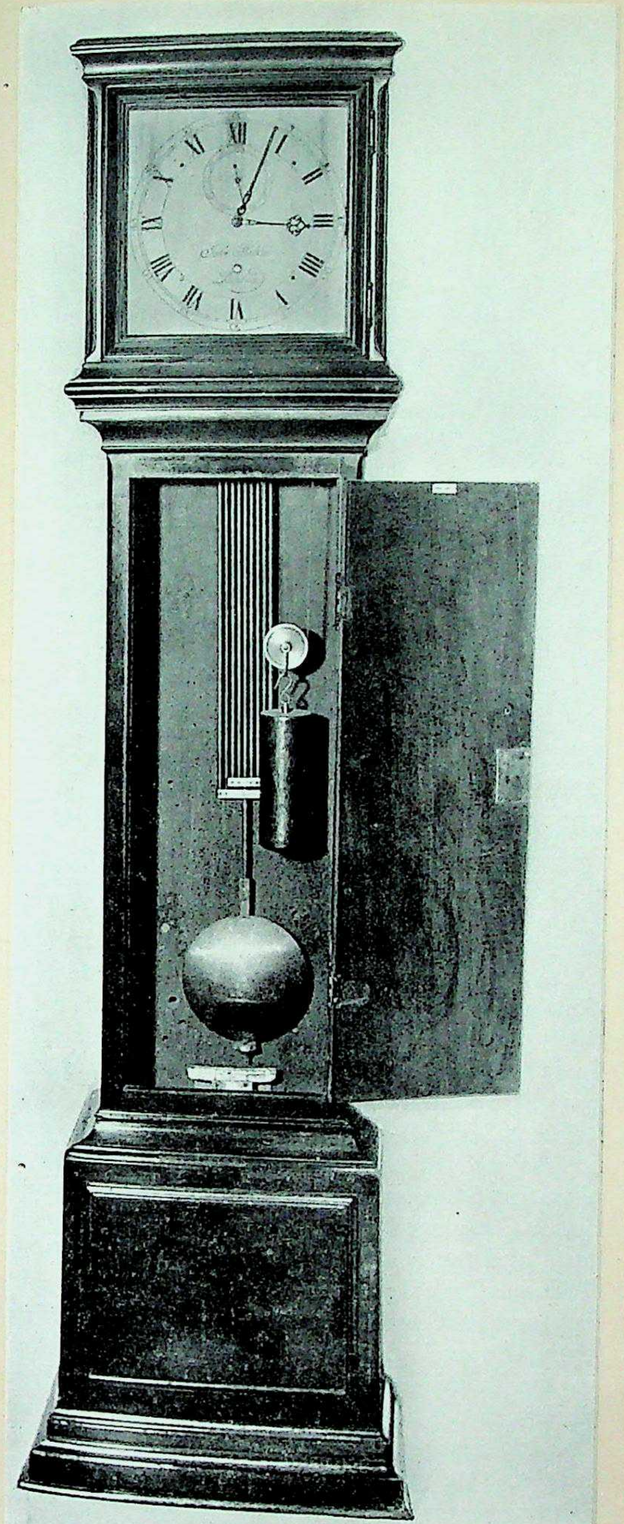


FIGURE 2 – *The clock made by John Shelton in 1760. The total height of the case is 5 ft 7½ in. The holes in the back-board were used for the clamps which held the gridiron pendulum in position on the clock's many journeys. Note the rating nut below the pendulum bob.*

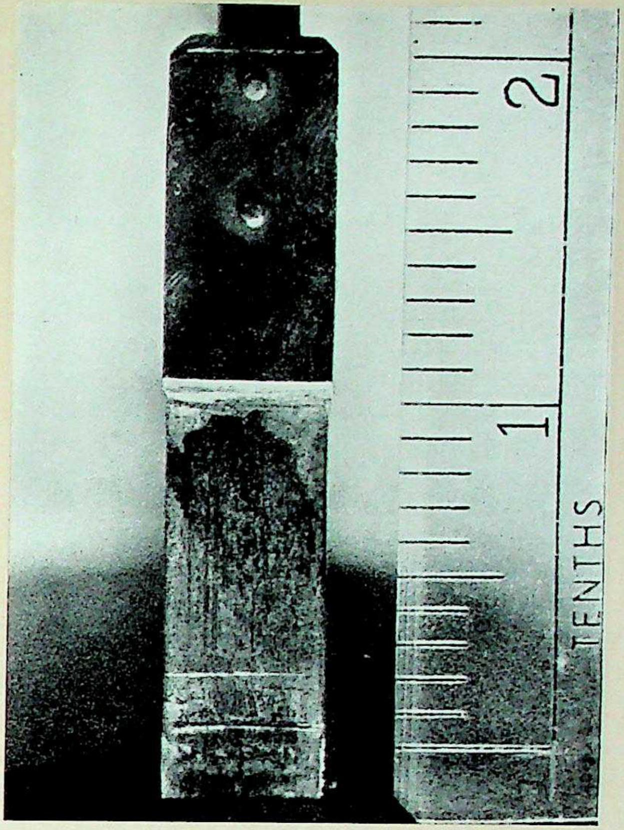
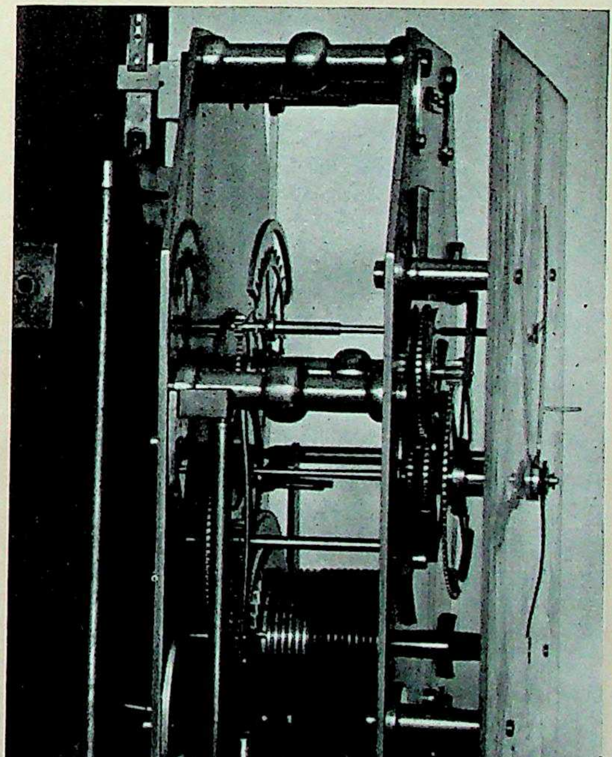


FIGURE 3 – *Marks made on the pendulum by Dr Bradley to indicate the correct position of the bob at Greenwich. The scale on the right is graduated in inches.*

FIGURE 4 (*right*) – *Side view of the mechanism of Shelton's clock.*



The Society's minutes of 5th May, 1768, record that 'Capt Campbell having mentioned that Capt James Cook,[1] who now attended, will be appointed by the Admiralty to the Command of the vessel destined for the Observations in the Southern Latitude. . . . Mr Cook was called in and he accepted the Employment.' Among the instruments allotted were 'An astronomical clock and an alarm clock now at the Royal Observatory. . . .'

At about the same time an expedition was being organized to go to Hudson Bay. The Society's minutes of 10th March record 'Ellicott's clock to go with the Observers at Hudson Bay.'

On 23rd June, 1768, instructions were given to Cook and to Mr Charles Green to go to the newly discovered island, King George's Island (Tahiti), to observe the transit of Venus: 'begin making your observations without any loss of time, remembering to put the bob of the pendulum at the same height exactly, as it was at the Royal Observatory at Greenwich before the voyage, by means of the marks made on the pendulum for that purpose, in order to find the difference in gravity, between Greenwich and your place of Observation. . . .' On 21st July, 1768, Cook and Green signed for 'An Astronomical Clock, an Alarm Clock, A Journeyman Clock. . . .'

The results of the expedition are given in the *Philosophical Transactions* for 1771. 'At Fort Venus, Royal Bay, King George's Island, 1769, April 15th. The astronomical clock, made by Shelton and furnished with a gridiron pendulum, was set up in the middle of one end of a large tent, in a frame of wood made for the purpose at Greenwich, fixed firm and as low in the ground as the door of the clock case would admit. . . . The pendulum was adjusted to exactly the same length as it had been at Greenwich. . . . The daily rate of the clock's losing on mean time . . . is 20·8 seconds. By the first and last day's observations compared together, the clock lost 19′ 49·9″ on mean time in 57 days, which is at the rate of 20·88″ or 20·9″ per day. . . .' Maskelyne adds a note: 'The same clock, when fixed up at the Royal Observatory at Greenwich, before the voyage, with a pendulum of the same length, got a rate of 1′ 45·8″ per day, on mean time, between April 19 and July 18, 1768. Therefore the force of gravity at Greenwich is to that at King George's Island as 1000000 to 997075.'

On 27th January, 1774, the council of the Royal Society selected the mountain of Schiehallion, in Scotland, for experiments to ascertain the extent of the deflection of a plumb-line caused by the attraction of the mountain mass, and thence to determine the mean density of the Earth. On 5th May of that year Maskelyne was asked to carry out the work. He took with him the 'astronomical clock by Shelton . . . which had been provided on occasion of the observations of the transit of Venus in 1761 and 1769.'

Lastly, the much travelled clock visited the Arctic regions. Parry, in his 'Journal of a Voyage for the discovery of the North West Passage, Performed in the years 1819–20 in H.M.S. *Hecla & Griper*, under Lieutenant Wm. Ed. Parry R.N., F.R.S.,' states in the Appendix, page 164: 'Two clocks were used in these experiments, being the property of the Royal Society, and the same which accompanied Captain Cook around the World.'

It is a great tribute to the skill of John Shelton that his clock, after so many vicissitudes and buffetings, should be still going today and recording time accurately. Of Shelton himself, Mr Robinson, lately librarian to the Royal Society, notes that he was born at Clerkenwell, London, in 1702. He was apprenticed to Henry Stanbury for seven years in 1712, and when free joined the Clockmakers' Company, being admitted by the Livery on 16th July, 1766. He worked for a long time for George Graham. Other clocks by him are at Greenwich Observatory, Armagh Observatory, and the History of Science Museum at Oxford. In spite of his skill and hard work he does not appear to have prospered, for on 22nd November, 1777, the president of the Royal Society presented to the Board of Longitude a petition by John Shelton in which he represented himself, his wife, and his family as 'totally destitute and in a very helpless condition and therefore praying for relief.'

The clock is illustrated by permission of the Royal Society. Figures 3 and 4 are by Mr Kaye, librarian of the Royal Society.

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[1] The rank of Captain here given to Cook was a courtesy one, though he had commanded various sloops before this date. Actually he was commissioned as Lieutenant for the command of the *Endeavour*. He was not promoted Captain until 1775.

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Snow crystals, natural and artificial

B. J. MASON

Although the delicate beauty of snow crystals, when seen under the microscope, has been known for many years, it is only comparatively recently that the mechanism of their formation has been studied. This article includes an account of a novel method of making permanent records of snow crystals by preparing plastic replicas, and gives an original theory of their growth. It appears that snow crystals react strongly to their environment, and present a faithful, though complicated, record of the changing conditions in the parent cloud.

The collection, examination, and classification of snow crystals has provided a fascinating field of study for many years, observations having revealed their great variety of shapes and forms. Until a very short time ago, however, little progress had been made in explaining this diversity, and in relating the external morphology of the crystals to the conditions of the environment. Early attempts to correlate the relative frequencies of the various crystal forms with the temperature at the place of observation gave inconclusive results, since only the conditions prevailing during growth of the crystals are relevant. The necessary information has recently become available, with the collection of snow crystals from all types of clouds having widely different conditions of temperature, supersaturation relative to ice, and vapour concentration.

As a complementary line of investigation, one may study the growth of ice crystals under carefully controlled conditions. It is, however, extremely difficult to simulate atmospheric conditions in the laboratory, and particularly to provide a realistic environment over a sufficiently long fall-path for the crystals to attain the size and complexity of the larger natural crystals. The simpler crystals, however, can readily be produced, though in miniature, by methods to be described later.

THE FORMATION OF SNOW CRYSTALS IN THE ATMOSPHERE

The ice elements formed in natural clouds are of three main types—individual ice crystals (or groups of crystals having a common nucleus), snowflakes, and hailstones. Every ice particle originates from a nucleus which may consist of a frozen cloud-droplet or a solid insoluble particle covered by a thin film of water which subsequently freezes. The properties and behaviour of these nuclei have been the object of considerable research [1]. After nucleation, the ice crystals continue to grow, in an atmosphere supersaturated relative to ice, by the diffusion of water vapour to their growing surfaces. They may exist as individual units of simple geometrical shape (e.g. hexagonal plates and prisms), or, under suitable conditions, may grow rapidly as dendritic forms into richly branching stellar crystals, several of which may collide and coalesce to form a snowflake.

There is a marked correlation between the external forms of the crystals and the characteristics of the parent cloud. The dominant crystal forms of the various cloud-types are shown in table 1, which is based largely on the observations of Weickmann [2]. The dominant crystal habit at temperatures below − 25° C is the hexagonal prism (figures 13–16), which is indigenous to the high- and medium-level clouds. Those crystals which grow under conditions of high ice-supersaturation are generally distinguished by the presence of hollow cavities (figure 13), which are generally absent in the prisms collected from cirrostratus, where only slight supersaturations exist. At higher temperatures, the prisms give way to thin hexagonal plates, examples of which are shown in figures 7 and 18. In falling through the cloud, both plates and prisms may sweep up supercooled droplets which freeze on impact and endow the crystal surface with a rimed appearance (figures 9, 10, 15, 16). In a dense cloud containing a high concentration of droplets, the collisions are so frequent that the crystals quickly develop into irregular aggregates of soft hail or graupel (figure 17), which will attain a considerable size if the upcurrents of air support them in the cloud long enough; they are produced mainly in convective clouds. When a plate-crystal exceeds a certain diameter (~ 0·2 mm) it may, under suitable conditions, sprout at the corners to form a star-shaped crystal (figures 7–9). The arms of the star may propagate secondary branches to produce intricate

TABLE I

Classification of ice crystals according to shape, cloud type, and environmental conditions. (Based on Weickmann's observations [2].)

Crystal form	*Cloud type*	*Temperature* (° C)	*Humidity*[1] (*per cent. relative to ice*)	*Vapour pressure*[1] (*mb*)
Hollow prisms (mainly clusters)	Cirrocumulus Cirrus castellatus Cirrus uncinus	− 30 to − 50	135–165	0·50–0·06
Complete prisms	Cirrostratus	− 25 to − 50	75–100 (Water) 95–165 (Ice)	0·60–0·06
	Altostratus Altocumulus	− 25 to − 50	125–165	0·80–0·06
Thick plates	Altocumulus Altostratus	− 15 to − 25	115–125	1·9–0·80
Thin plates	Nimbostratus Stratus Stratocumulus	0 to − 15	100–115	6·0–1·9
Stars Needles (Dendritic forms)	Nimbostratus Stratocumulus	0 to − 15	100–115	6·0–1·9

[1] Calculated on the assumption that water saturation exists in all clouds except cirrostratus.

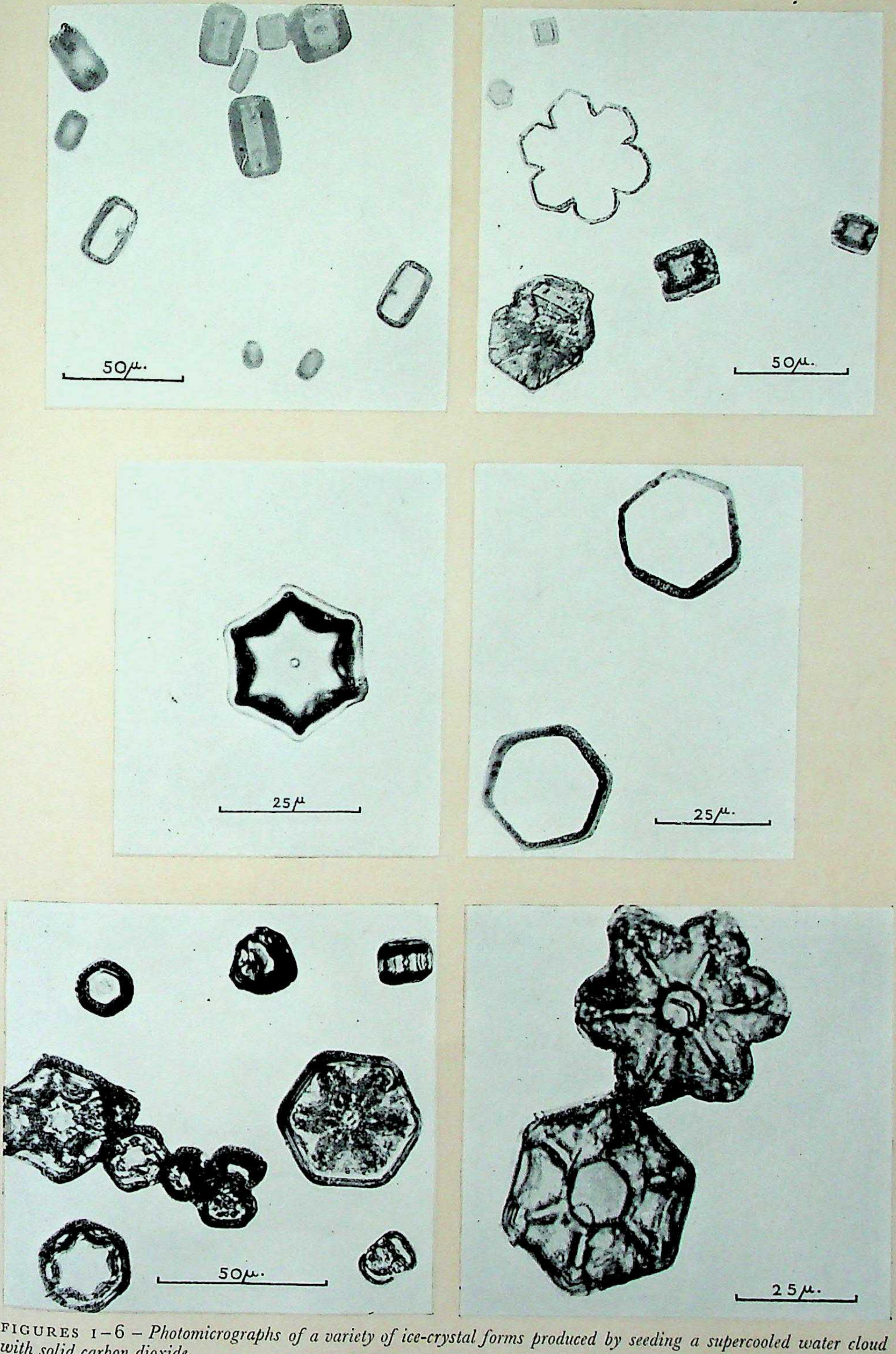
patterns of great beauty (figures 8–11). This secondary growth may continue until the spaces between the arms of the star become filled, except for small enclosed hollows, so forming a large plate-like structure, in the centre of which the original hexagonal crystal may often be identified (figure 9).

Snowflakes consist of a rather haphazard agglomeration of loosely interlocking crystals (figure 12). The individual components can often be identified and separated, which suggests that the flake is built up as a result of collision and subsequent coalescence of individual crystals having different terminal velocities; this process is greatly facilitated if the surfaces of the crystals are wet. Large snowflakes are thus to be expected when dendritic crystals are formed in 'warm' clouds of high vapour content (temperatures above about − 15° C) and fall into still warmer regions where coalescence occurs. In 'cold' clouds of low water content individual crystals will predominate.

Figures 7–12 and 14–18 show the form of some typical snow crystals which were caught at ground level during December 1950. They are, in fact, microphotographs of plastic replicas of the actual crystals, obtained by an ingenious technique devised by Schaefer [3]. A 1 per cent solution of Formvar (a polyvinyl acetal resin) dissolved in ethylene dichloride is kept at a temperature of about − 5° C. A clean microscope slide is immersed in the solution for about 30 seconds and then exposed horizontally to the falling crystals. A captured crystal becomes submerged in the solution, and if the slide is kept at sub-freezing temperature for a few minutes the solvent evaporates, leaving the crystal encased in a thin but tough plastic shell. Once the solvent has evaporated the slide may be exposed to room temperature, when the crystal will melt, the water diffusing out through the plastic membrane as it evaporates, to leave a replica which retains in microscopic detail all the surface configurations of the original crystal (see especially figures 7–11). The crystals are also easily caught on a black cloth, when replicas of selected specimens can be made by touching them gently with a plastic-coated slide. The replicas may be stored indefinitely and photographed at leisure. Figures 7–12 and 14–18 were obtained by photographing the replicas through a low-power microscope, using reflected light.

PRODUCTION OF ICE CRYSTALS IN THE LABORATORY

Small crystals of less than 50 μ diameter, yet possessing many of the characteristics of natural


50μ.
50μ.
25μ
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50μ.
25μ.

FIGURES 1–6 – *Photomicrographs of a variety of ice-crystal forms produced by seeding a supercooled water cloud with solid carbon dioxide.*

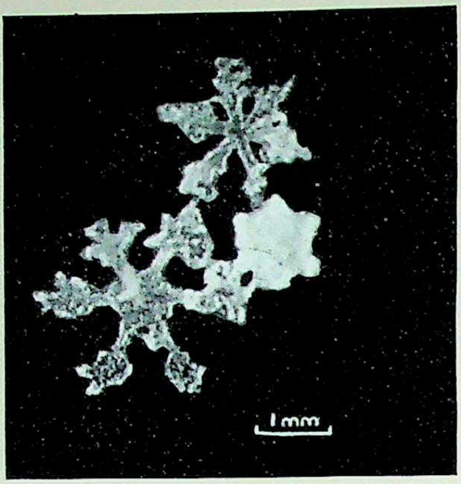


FIGURE 7 – *Crystals showing early stages of dendritic growth, and a single plate covered with rime.*

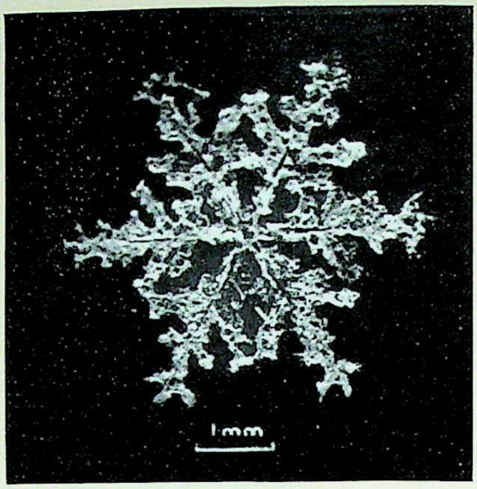


FIGURE 8 – *A crystal showing advanced dendritic growth.*

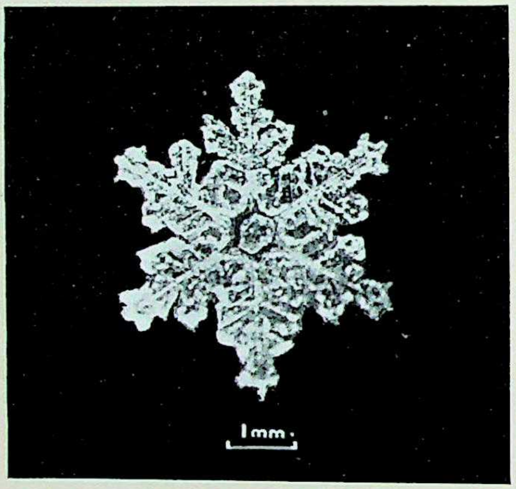


FIGURE 9 – *A stellar crystal showing the hexagonal plate at its centre.*

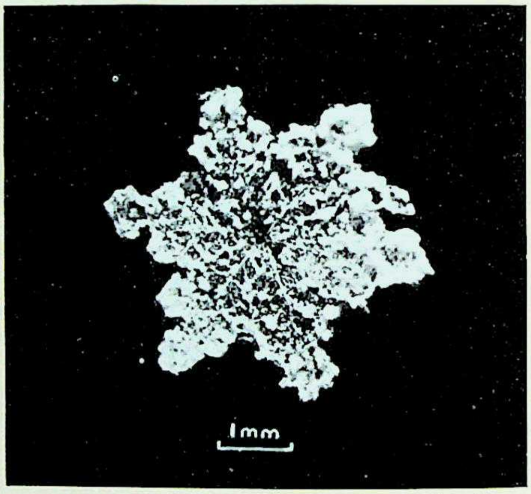


FIGURE 10 – *A stellar crystal covered with frozen droplets.*

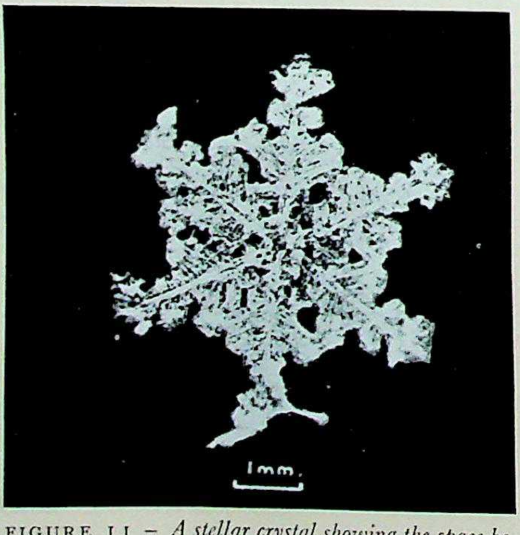


FIGURE 11 – *A stellar crystal showing the space between the arms filled in, except for small enclosed hollows.*

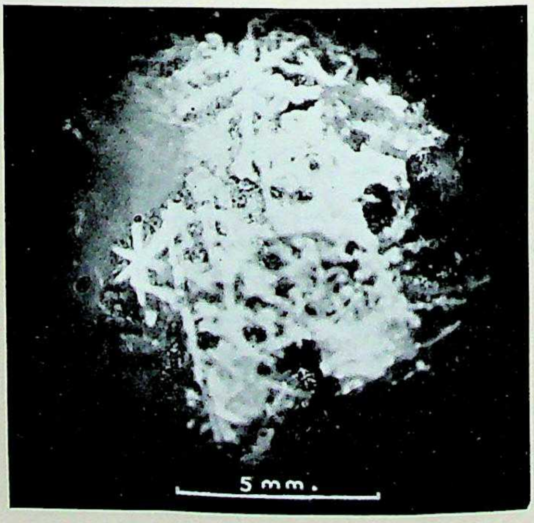


FIGURE 12 – *A snowflake composed mainly of interlocking stellar crystals.*

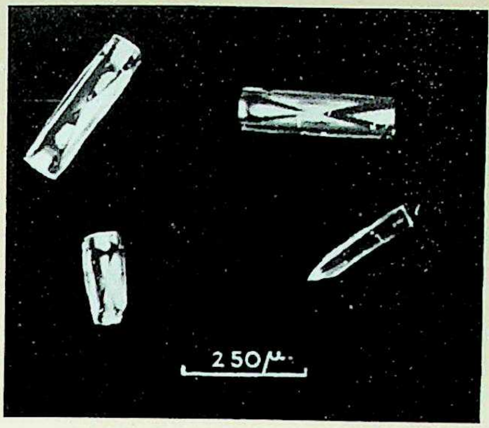


FIGURE 13 – *Hollow prismatic crystals (after Weickmann* [2]).

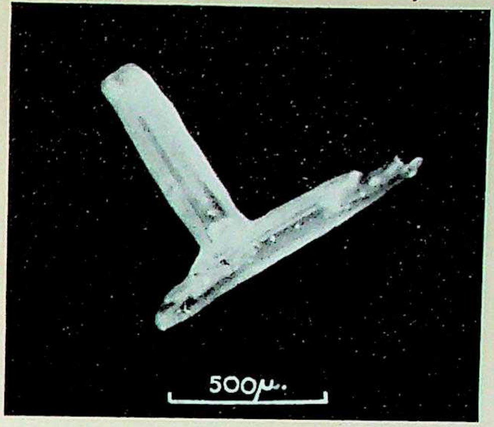
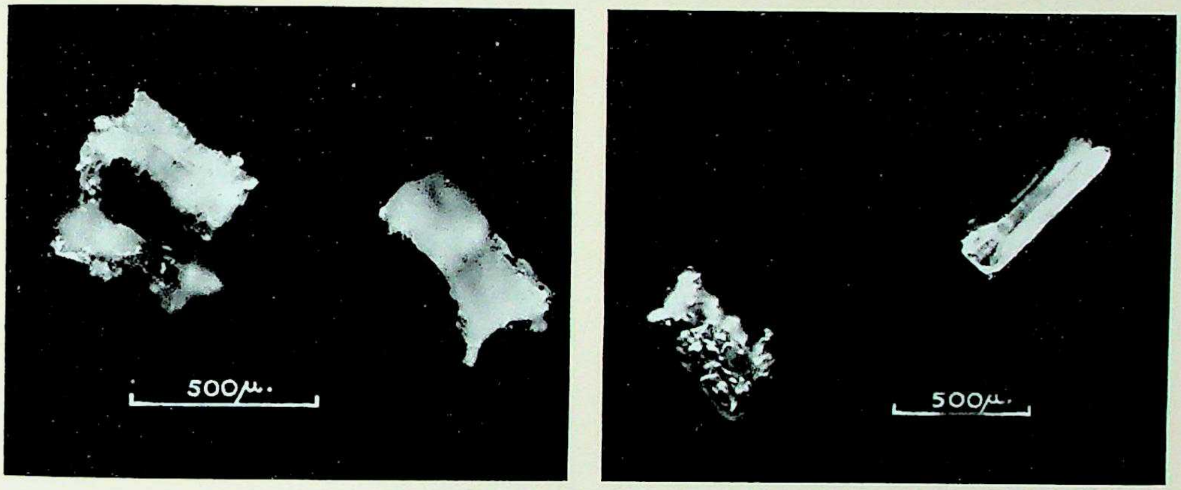


FIGURE 14 – *Large prismatic columnar crystals.*



FIGURES 15 *and* 16 – *Prismatic crystals covered with frozen droplets (rime).*

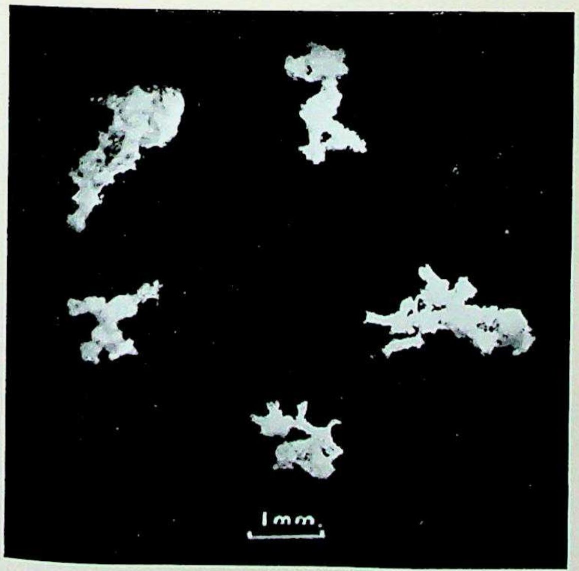


FIGURE 17 – *Pellets of soft hail.*

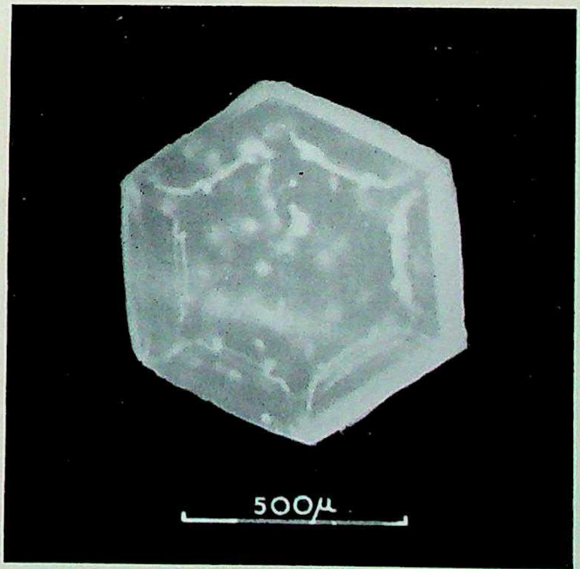


FIGURE 18 – *A single hexagonal plate.*

crystals, may be produced in vast numbers with extremely simple apparatus. The method is to produce a cloud of minute supercooled water droplets in a cold chamber and to transform this into a cloud of small ice crystals by introducing a seeding agent.

One simple apparatus used by the author consists of a thermally insulated double-walled copper chamber, of some 20 litres internal capacity; the lower half of the annular space is filled with a cooling mixture of petrol and solid carbon dioxide. The bottom of the chamber may thus be cooled to about − 45° C, though − 20° C is a convenient temperature for most experiments. The chamber may be used with the top open, the strong temperature inversion making the air inside very stable. A supercooled cloud may be produced by breathing into the chamber or by evaporating water from a small container. The cloud, which is composed of droplets of some 10 μ diameter, at a concentration of a few hundreds per cubic centimetre, is illuminated by a powerful parallel light beam, the walls of the chamber being lined with black velvet to provide dark background illumination. As a more convenient, but much more expensive, form of this apparatus one may use a thermostatically controlled low-temperature refrigerator.

At − 20° C the supercooled water cloud persists for several minutes, and only an occasional ice crystal is seen to glitter in the light beam. If, however, any part of the chamber is cooled below about − 40° C, large numbers of ice crystals appear, the water fog being transformed completely into ice crystals within a few seconds.

Schaefer [4] claims that the transition is very sharp, a pellet of mercury (melting point − 38·9° C) leaving ice crystals in its wake as long as it remains solid, but not after the instant of melting. He interprets this temperature as the critical temperature at which ice crystals arise spontaneously from the vapour. It seems difficult, however, to associate such a statistical event with a sharp transition temperature. In fact, the present author [8] finds that only a very few ice crystals appear at − 39° C, and that the number increases rapidly with falling temperature, very large numbers being formed at − 41° C. It seems that the rapid chilling produces a momentary supersaturation high enough to cause spontaneous condensation, and that the droplets quickly evaporate unless they freeze spontaneously into crystals which, even at the original temperature, are in a supersaturated atmosphere and therefore survive and continue to grow to visible size. This view is supported by the fact that small water droplets ($\sim 10\ \mu$) suspended in air freed from foreign nuclei can be cooled down to $-40{\cdot}5 \pm 1{\cdot}5°$ C before freezing [5].

The transition from a supercooled water cloud to an ice cloud may be demonstrated in a very striking manner by scratching a single tiny speck from a piece of solid carbon dioxide (temperature about − 65° C) into the chamber. The track of the pellet first shows as a thin white streak, which broadens rapidly and after a few seconds takes on the beautiful appearance of a condensation trail; this may be compared with the trail left by an aircraft. The appearance of the lower edge of the trail suggests that the pellet of carbon dioxide, by cooling the top of a thin layer of air, has caused it to become unstable and to break up into small pockets of cold air which carry some of the minute crystals downwards.

At this stage, countless numbers of tiny ice crystals can be seen glittering in the vicinity of the trail, and within a few seconds they become dispersed throughout the cloud by local convection currents and turbulence. As the equilibrium vapour pressure over a water surface exceeds that over an ice surface at temperatures below 0° C, the mixed cloud of water droplets and crystals is colloidally unstable; the droplets evaporate and the vapour sublimes on to the crystals, which grow quite rapidly and fall to the bottom of the chamber. The above experiment demonstrates very clearly those physical processes which are fundamental to the release of precipitation from the majority of natural clouds, and also exactly what happens when pellets of solid carbon dioxide are dropped into clouds with the object of inducing precipitation artificially. A small speck of solid carbon dioxide may produce some 10^7 crystals when introduced into a supercooled cloud at − 20° C. Photomicrographs of replicas of some typical crystals, which in this case were viewed by transmitted light, are shown in figures 1–6. They consist for the most part of small hexagonal plates and short hexagonal prisms, and are in many respects just miniatures of similar atmospheric crystals. Although the dimensions of many crystals are only a few microns, the replicas reveal detailed surface markings and internal cavities.

THEORY OF SNOW CRYSTAL GROWTH

An attempt has recently been made by the author [6, 7] to explain the development of the various crystal forms in terms of their molecular

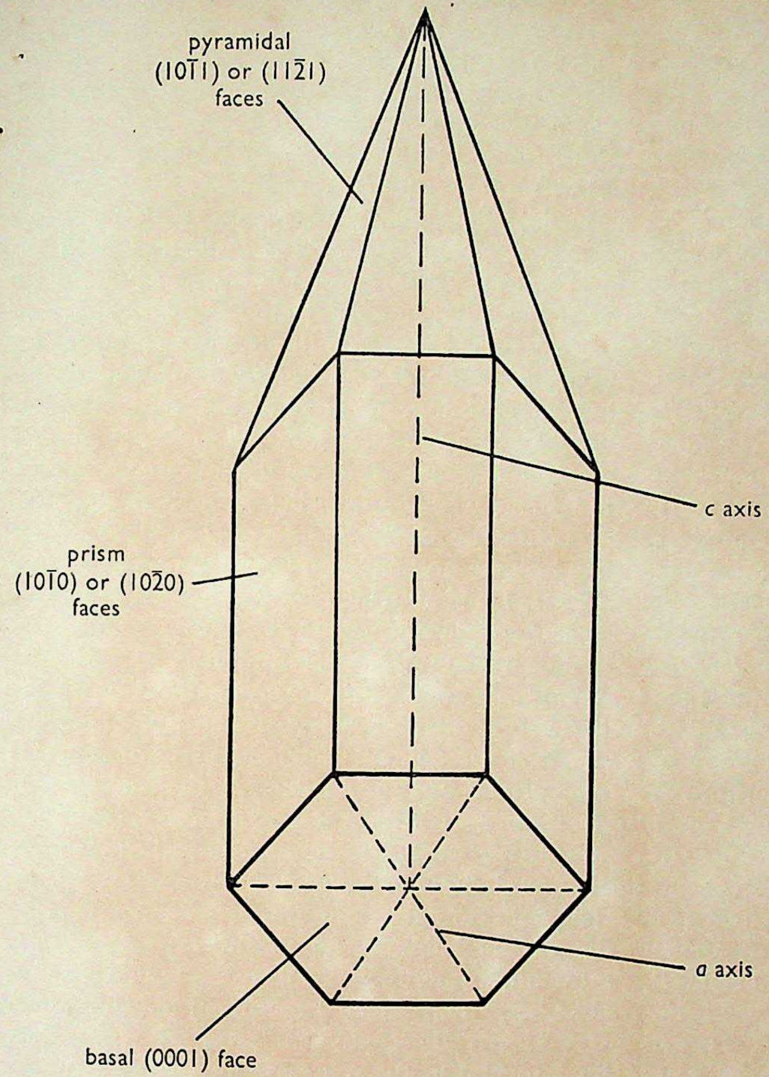

pyramidal
(10$\bar{1}$1) or (11$\bar{2}$1)
faces
c axis
prism
(10$\bar{1}$0) or (10$\bar{2}$0)
faces
a axis
basal (0001) face

FIGURE 19 – *The crystallographic faces of ice.*

and surface structures, their fall-motion, and the meteorological conditions in the parent cloud.

The rate of growth of a snow crystal is determined by the rate of arrival of vapour by diffusion, and by the rate at which the molecules can be assimilated into the surface structure, which in turn is controlled by the rate at which the latent heat of crystallization can be dispersed, mainly by conduction through the air. The computation of the growth-rate of, say, a falling plate-crystal is a difficult problem. If, as a first approximation, its surface is regarded as an equipotential, and the fall-motion of the crystal is neglected, the rate of increase of mass m is given by

$$\left(\frac{RT}{DMP}+\frac{L^2JM}{KRT^2}\right)\frac{dm}{dt}=8r\sigma \quad \ldots\ldots \ (1)$$

where M is the molecular weight of ice, D the coefficient of diffusion of water vapour in air, K the thermal conductivity of air, P the vapour pressure, σ the supersaturation, T the temperature, R the gas constant, L the latent heat of crystallization, J the mechanical equivalent of heat, and r the crystal radius. The rate of increase of mass of a plate-crystal is thus less than that of a sphere of equivalent radius by a factor of $2/\pi$. The lines of diffusive flux will be concentrated at the edge of the disk, so that its thickness x will increase only very slowly; assuming it to remain constant, the rate of change of radius is given by

$$\left(\rho\frac{RT}{DMP}+\frac{L^2JM}{KRT^2}\rho\right)\frac{dr}{dt}=4\sigma/\pi x \ ..(2)$$

where ρ is the crystal density. At $T = 260°$ K and water-saturation, and with $x = 10\ \mu$, $dr/dt \sim 7 \times 10^{-5}$ cm sec^{-1}, so that the crystal will grow to a radius of $100\ \mu$ in about 150 seconds. The growth-rate will be slightly greater than predicted by equation 2 if the crystal is falling.

From the molecular structure of ice, as revealed by X-ray and neutron diffraction, it appears that its mean crystalline structure belongs either to the dihexagonal-bipyramidal (D^4_{6h}) or to the ditrigonal-bipyramidal (D^4_{3h}) space group. The dominant growth-forms to be expected are therefore hexagonal prisms, hexagonal bipyramids, and hexagonal prisms with pyramidal ends (see figure 19). The external morphology of a crystal is determined, however, by the relative rates of growth of the different faces; the pyramidal faces, being of lower atomic density (i.e. of high index), will in general grow faster than the basal and prism faces, and so tend to grow out. The dominant crystal habit of an ice crystal should therefore be a hexagonal prism bounded by the slow-growing (0001) and (10$\bar{1}$0) or (11$\bar{2}$0) faces, and this is certainly the most common basic shape among atmospheric crystals. The pyramidal faces may persist for some time when the crystal is growing slowly; in fact the formation of certain rare haloes in cirrostratus can be explained by the refraction of light in pyramidal crystals.

The prismatic crystals which predominate below -25° C develop as a result of preferential growth along the principal (c) axis, i.e. normal to the basal (0001) face. It is suggested that the most important factor in determining the relative rates of growth of different faces is the relative rates at which molecules diffuse along the surfaces towards their respective growth-fronts; this in turn will be controlled largely by the activation energy which is necessary for a molecule to jump over the potential peaks of the surface field. Exact calculations of the fields of force at the various crystal faces of ice have not yet been made, but there is indirect evidence that the coefficient of surface diffusion will be greater on the basal face. Hence, given an equal current of molecules to both faces, the basal face will be propagated faster than a prism face, leading to the development of prismatic columns.

The plate-crystals, on the other hand, are produced as a result of the growth normal to the basal face being overshadowed by a much more rapid development in the direction of the secondary (a) axis. Weickmann [2] has suggested that at higher temperatures the molecules striking the basal face do not form a new layer but diffuse across the face and are built into the crystal structure only at the edges. The fact that molecules migrate from one crystal face to another is now well established, and it can be shown that the ratio between the rates of propagation of the edges of the crystal by surface diffusion from the basal faces and by direct deposition from the vapour is given by $2\lambda/x$, where λ is the average distance a molecule travels on the surface before evaporating, and x is the thickness of the plate. Surface diffusion will be the dominant process if $x < 50\ \mu$. The thin ice plates formed at temperatures above -20° C have thicknesses of about $10\ \mu$, so that migration of molecules from the basal faces to the edges may be a significant factor in their development. This effect will be reduced at low temperatures, as indicated by the formation of 'glassy' ice at temperatures below about -70° C. Once the plate-like development has begun it will be further assisted by the concentration of the lines of diffusive flux towards its edges.

The dendritic stellar crystals often arise from small hexagonal plates, the corners of which shoot out to form the arms of the star. Such a development marks the beginning of dendritic growth, as opposed to the ordered development of crystal faces leading to polyhedral growth, which occurs only if the diffusion field is not disturbed appreciably from its equilibrium state. The falling crystal will, however, disturb the field, which will strive to return to its equilibrium pattern with a speed determined by the coefficient of diffusion. If, however, the crystal falls at an appreciable speed, non-uniform gradients will be set up, and the rate of arrival of vapour at the crystal surface will be reduced. If the material is extracted from the field faster than it can be replaced by diffusion, the concentration in the immediate neighbourhood of the crystal will fall below the equilibrium value and only the corners will grow, since they protrude into regions of higher concentration. Polyhedral growth thus breaks down and dendritic growth begins. The diffusion field will now reorganize itself and become highly convergent towards the growing tips, which also will be preferred sites for the dissipation of the latent heat of crystallization. The criterion for the onset of dendritic growth must express the much greater tendency for the diffusion field to be disturbed by the falling crystal than for it to return to its equilibrium condition. The author [7] shows this criterion to be $vr/D \gg 1$, where v is the velocity of the crystal relative to the air, r the crystal radius, and D the coefficient of diffusion. The terminal velocity of small hexagonal plates in still air is about 30 cm sec^{-1}, and $D \sim 0{\cdot}3$ cm^2 sec^{-1}; thus dendritic growth will set in only when r considerably exceeds 0·1 mm, which is in good agreement with observation. In order to grow into large dendritic structures the crystals must spend a considerable time in a cloud of high vapour-concentration; in view of their relatively high speeds of fall, the cloud must also be of considerable depth. Snow crystals appear to react strongly to their environment, and to present a faithful, if complicated, record of the changing conditions in the parent cloud.

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The analysis of inorganic compounds by paper chromatography

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Although inorganic analyses on strips of absorbent paper were described a century ago, it is only within the last few years that the possibilities of the method have been closely examined. This overdue examination has proved very rewarding, and methods of separating a very wide range of mixtures of cations have been developed. The results are comparable with those achieved by orthodox analysis, but the methods are very much more economical of both time and material. It appears that similar techniques can be developed for anions.

Recent researches [1a] into the early history of chromatography indicate that the first recorded experiments on capillary analysis should be attributed to F. F. Runge, who, in 1850, analysed mixtures of dyes on blotting paper, and earlier had suggested spot tests for bleaching solutions, using dyed cotton fabric or paper impregnated with starch and potassium iodide. His interest also extended to the possibilities of using the capillary ascent of solutions in blocks of wood for the separation of solutes. At a later date this was more fully investigated by Goppelsroeder, a pupil of Schoenbein [1b]. The latter, who has usually been regarded as the pioneer of capillary analysis of inorganic compounds, showed that if a strip of paper is dipped into water containing inorganic salts, the water rises in the paper and carries the salts with it. The liquid front usually advances ahead of the inorganic cations, which move independently according to their relative rates of diffusibility. The types of separation achieved are illustrated in figure 1. Two simple techniques can be used. The first consists in dipping an inch-wide strip of filter paper, with a spot of the mixture of cations placed about one inch from the lower end, into a small beaker of water; the water is allowed to rise in the strip by capillary action. Some results obtained by this method are illustrated in figure 1 (*a*), (*b*), and (*c*). In the second technique one uses a disk of filter paper placed between two glass plates, about six inches square, gripped together by clips; the upper plate has a hole in the centre [2]. One drop of the mixture of cations is placed on the paper through the hole, and is followed by drops of water or other solvents, such as methylated spirit. This procedure has the advantage of being very quick, giving sufficient movement of the liquid front in about fifteen minutes, compared with several hours for other methods. Such disk-separations are illustrated in figure 1 (*d*) and (*e*). In general, the difference in the rates of diffusion of different cations is not sufficient to produce a clean separation, and the bands containing the cations are often very close together or overlapping. Nevertheless, with certain mixtures, for example of lead, silver, and nickel or cobalt, it is possible to get sufficient separation for purposes of identification (see figure 1 (*d*)). With some cations, hydrolysis may occur, and the solvent must be acidified to prevent it; the *p*H of the mobile phase may, therefore, be quite a critical factor. Hydrolysis may be used to separate the cation from the anion; with lead acetate, for example, the acetate anion will move away from the lead hydroxide, which is retained at the starting point. On the whole, the process is not so successful with inorganic salts as with materials like organic dyestuffs, which, as Goppelsroeder [3] showed, can be separated into distinct and completely detached zones.

TABLE 1

Reagents used to identify cations in the chromatograms illustrated in figures 1–3

Reagent	*Cations*
Rubeanic acid	Ni—greyish blue; Cu—olive green; Co—brown
Potassium chromate	Pb—yellow; Ag—brick red
Potassium thiocyanate	Bi—yellow
Potassium ferrocyanide	U—purplish brown; Fe—blue
Rhodizonic acid	Ba—bright red; Pb—violet
Phosphomolybdic acid	Sb—blue
Sodium hypophosphite	As—brown
Zinc uranyl acetate	Under ultra-violet light. Na—bluish-green fluorescence
Kojic acid and 8-hydroxyquinoline	Under ultra-violet light. Al—green fluorescence; Sn—yellow fluorescence.

NOTE. For further details see reference [12].

Schoenbein's work aroused the interest of

E. Fischer [4], who carried out a quantitative investigation of the separation of sodium and barium, and of certain double salts, on a column consisting of six individual rolls of filter paper packed closely together. He observed that some separation occurred, as is shown by the results quoted for a solution containing equal concentrations of barium and sodium chlorides:

Roll No.	1	3	5
$BaCl_2/NaCl$	1 : 1·022	1 : 1·230	1 : 1·364

He utilized this method in order to separate the cations in a double salt such as ferrous ammonium sulphate, thus demonstrating the absence of a complex ion.

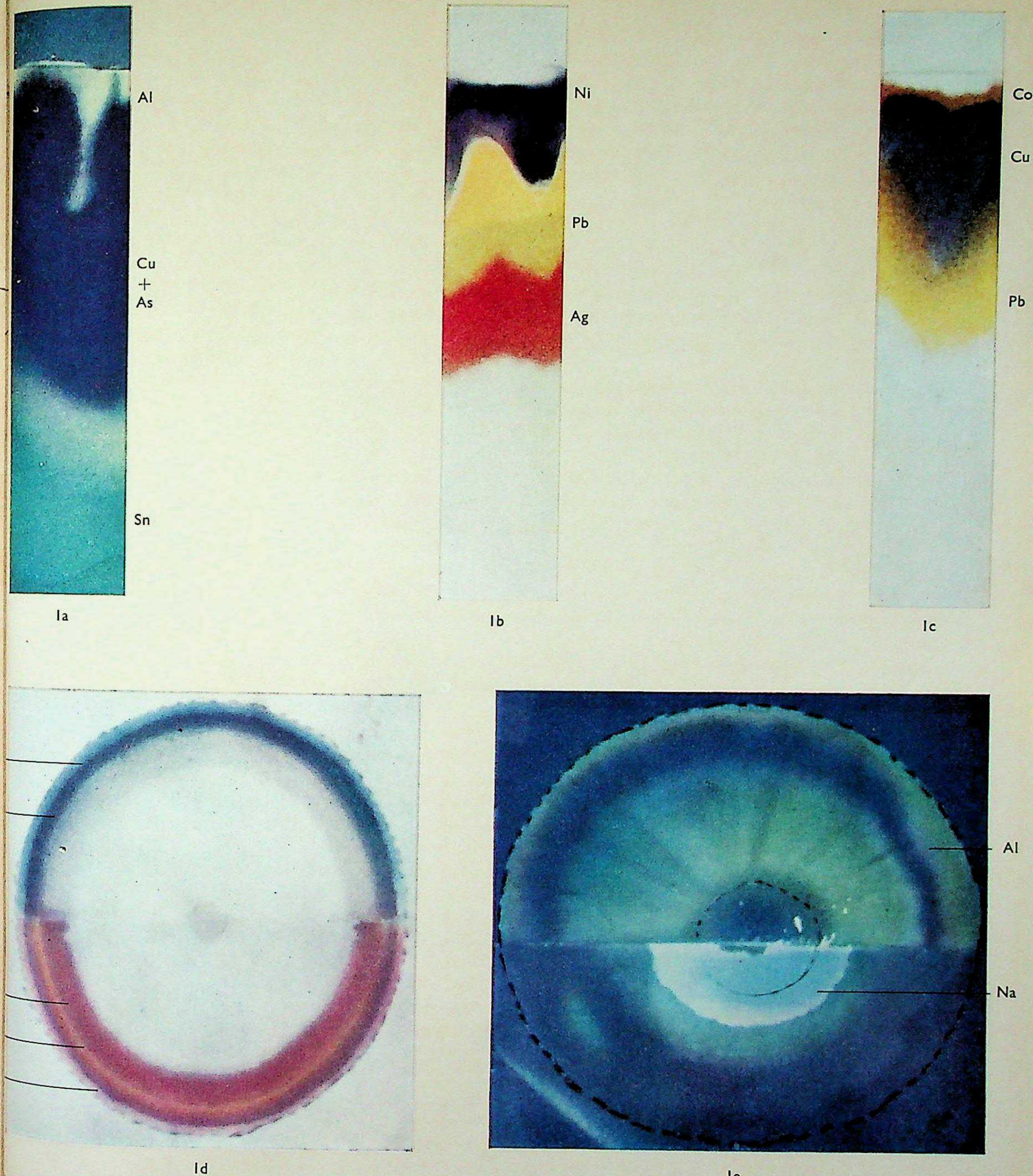
More recently, Flood [5] has carried out extensive researches on separations with paper impregnated with alumina, in which he has obtained zones of cations similar to those on alumina columns described by Schwab and Jockers [6]. The method consists in dipping an alumina-impregnated strip of paper into a solution of the cations and allowing the water to rise in it by capillary action. As the liquid rises, the more strongly adsorbed cations displace the weaker ones, which are pushed ahead, forming distinct zones. The process is essentially displacement chromatography, the length of the zone being proportional to the initial cation concentration. Flood has used this method to estimate quantitatively the strengths of solutions.

Except for the occasional use of capillarity for certain microchemical tests, no marked advances were made until recently, when a number of independent workers, inspired by the outstanding successes in organic chemistry of the Martin and Synge [7] partition techniques, reinvestigated these methods. The basis of the separation of organic substances was that of differential partition between an organic solvent and water, the latter being carried on an inert support such as cellulose—often in the form of filter paper—as a diffusion medium. While the procedures employed for inorganic compounds resemble those for organic compounds, there is no crucial experimental evidence to suggest that the separations are entirely due to differential partition. Some of the procedures described, however, such as the separation of uranyl nitrate using ether as solvent, do apparently depend essentially on selective extraction. To what extent adsorption or exchange is involved in the separations is still not at all clear, though it may be that dipolar interaction occurs between hydrated ions and the imbibed water on the cellulose of the same type as that suggested by Sacconi [8] for alumina. This aspect of the function of the cellulose support has been discussed by Hanes and Isherwood [9]. Some workers recommend special conditioning treatment for the cellulose, but for the solvent mixtures employed by us we have found that no advantages accrue from such treatment. All the examples illustrated here were obtained with untreated Whatman No. 1 filter paper. The important point is that, whatever the mechanism concerned, the behaviour of the inorganic compound in a particular chromatogram is definitely reproducible, except where, in the presence of certain other compounds, displacement occurs. Such displacements as we have noticed are not very serious, and often bring about an improved separation.

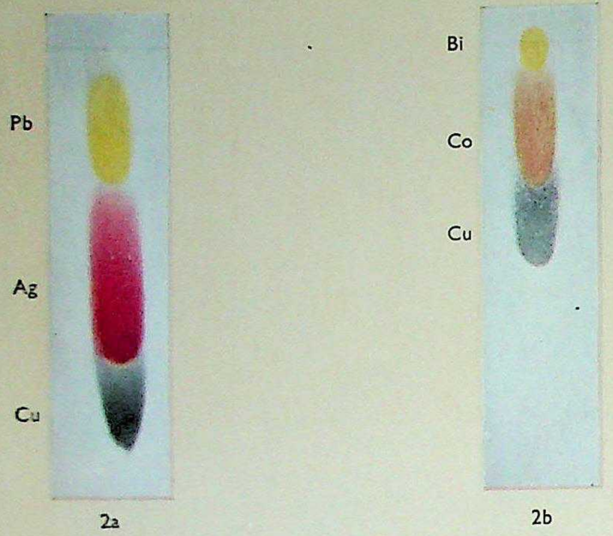
The movement of the compounds is conveniently expressed in terms of their R_f value, which measures their rate of movement relative to the liquid front. The R_f value is a constant for a particular cation with a particular solvent-mixture as the mobile phase, provided that all essential conditions, notably grade and condition of paper, temperature, distance moved by the solvent front, and *p*H of the mobile phase are maintained constant.

For qualitative work the apparatus and general procedure are based on those of Martin and Synge. A trough of glass or plastic material is supported in a glass tank which can be made airtight by a glass plate. The solvent is put in the trough, and a sheet of filter paper, with spots of the solution to be analysed placed on a line drawn about two inches from the top of the paper, is hung with the upper end dipping into the solvent. The solvent siphons over and down the strip, and, when the solvent front is about an inch from the bottom of the paper, the sheet is removed, dried, and sprayed with the reagents necessary for the identification of the various ions. Provided that adequate precautions are taken to keep the paper reasonably taut, upward movement of the solvent, like that used originally by Schoenbein, and the disk method can both yield good chromatograms.

The choice of solvent mixture for the mobile phase determines the extent, and often the order, of separation of the inorganic cations. Many different types of organic liquids have been tried, but the choice of new solvents for investigation will depend upon the particular cations in the initial mixtures, and upon the kind of process, namely extraction or partition, which is considered to be responsible for the separation.

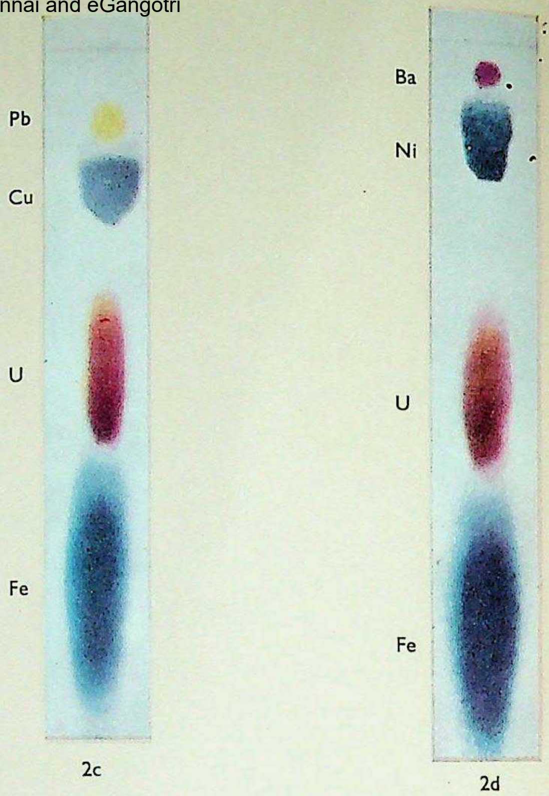


IGURE 1 – *Fairly good separations of some metals can be obtained on filter paper by capillary action, using water or solvents like methy-ated spirit as the developing liquid. The examples illustrated show that the bands are usually close together and often overlap. Similar esults are obtained with either the strip (figure* 1a, b, *and* c) *or the disk (figure* 1d *and* e) *techniques, but the latter is much quicker.*



2a

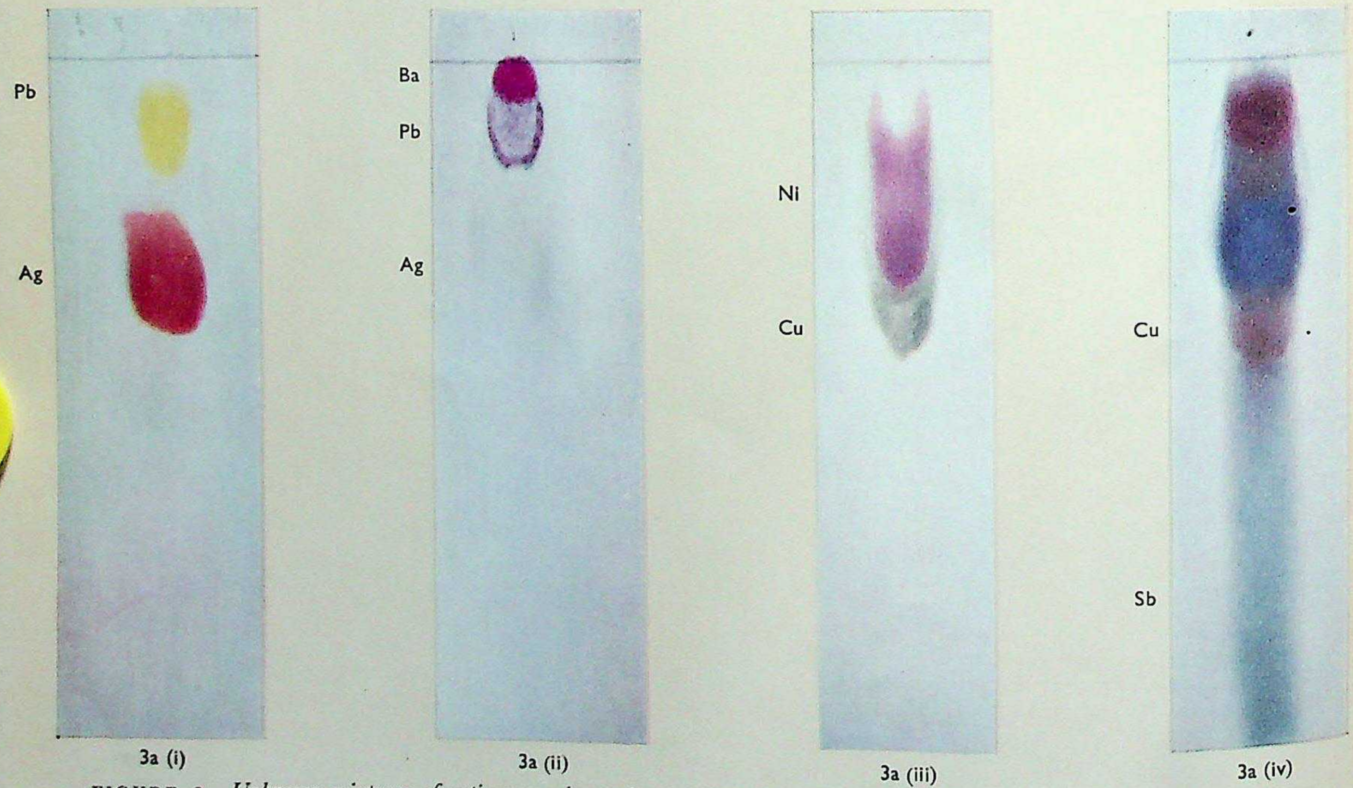
2b



2c

2d

FIGURE 2 – *Separations by partition chromatography show much clearer bands, usually some distance apart. The use of a complexing agent in the mobile phase (e.g. benzoylacetone in aqueous butanol) facilitates the separations, since the various metal complexes are likely to have markedly different partition coefficients for distribution between the water and the organic solvent. The order of separation is different from that with water alone.*



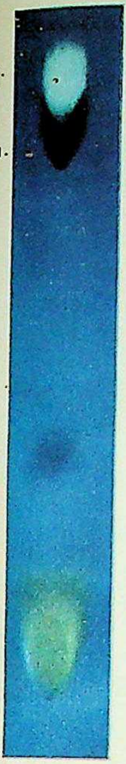
3a (i)

3a (ii)

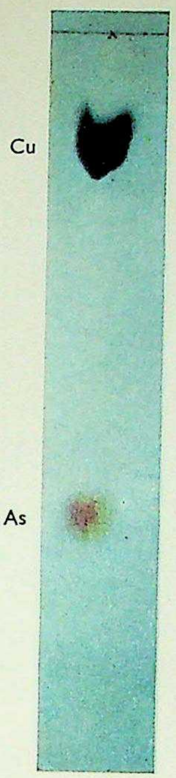
3a (iii)

3a (iv)

FIGURE 3 – *Unknown mixtures of cations can be analysed by using a suitable series of identification tests on a number of similarly prepared chromatograms (see table I).* (a i–iv) *Mixture of Ag, Pb, Ni, Cu, Sb, and Ba;* (b i and ii) *mixture of Al, Cu, As, and Sn;* (c i–iii) *mixture of Al, Na, U, Fe, and Sn. The mobile phase used here was a mixture of benzoylacetone and aqueous butanol.*



3b (i)



3b (ii)

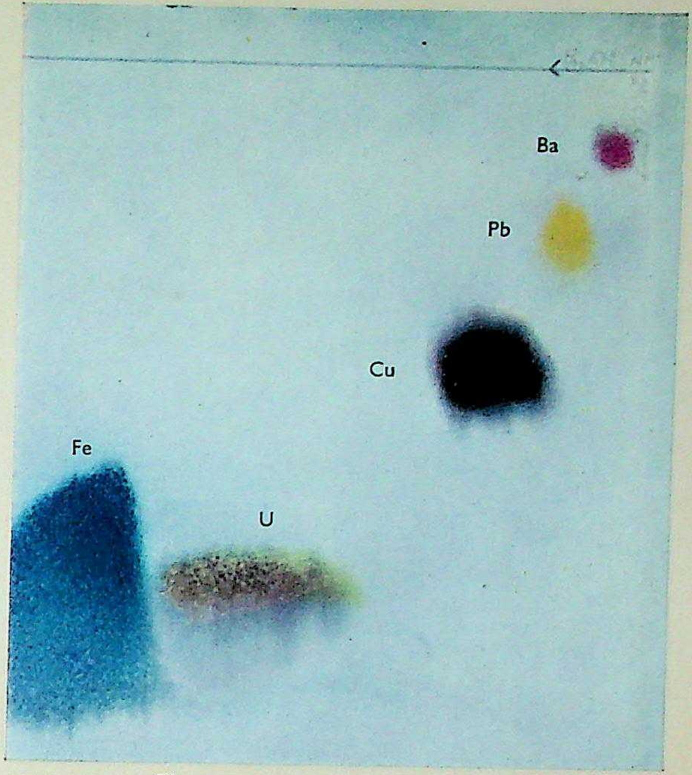
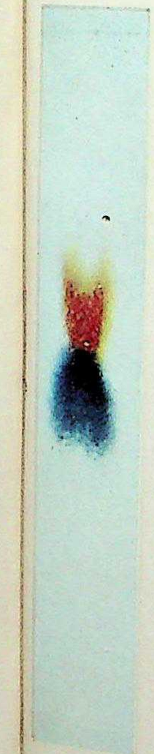
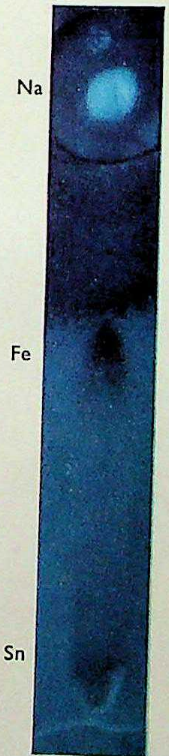


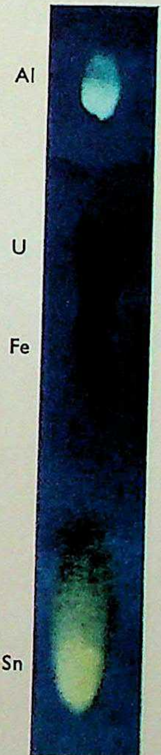
FIGURE 4 – *Two-way separations can often produce improved chromatograms. The example shows a chromatogram prepared in one direction with aqueous butanol containing benzoylacetone, and in the other with aqueous butanol containing trichloracetic acid.*



3c (i)



3c (ii)



3c (iii)

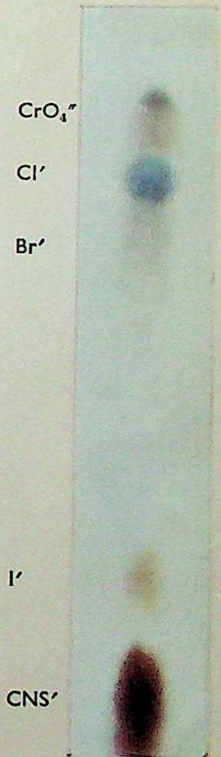

CrO₄″
Cl′
Br′
I′
CNS′

FIGURE 5 – *Some anion separations.*

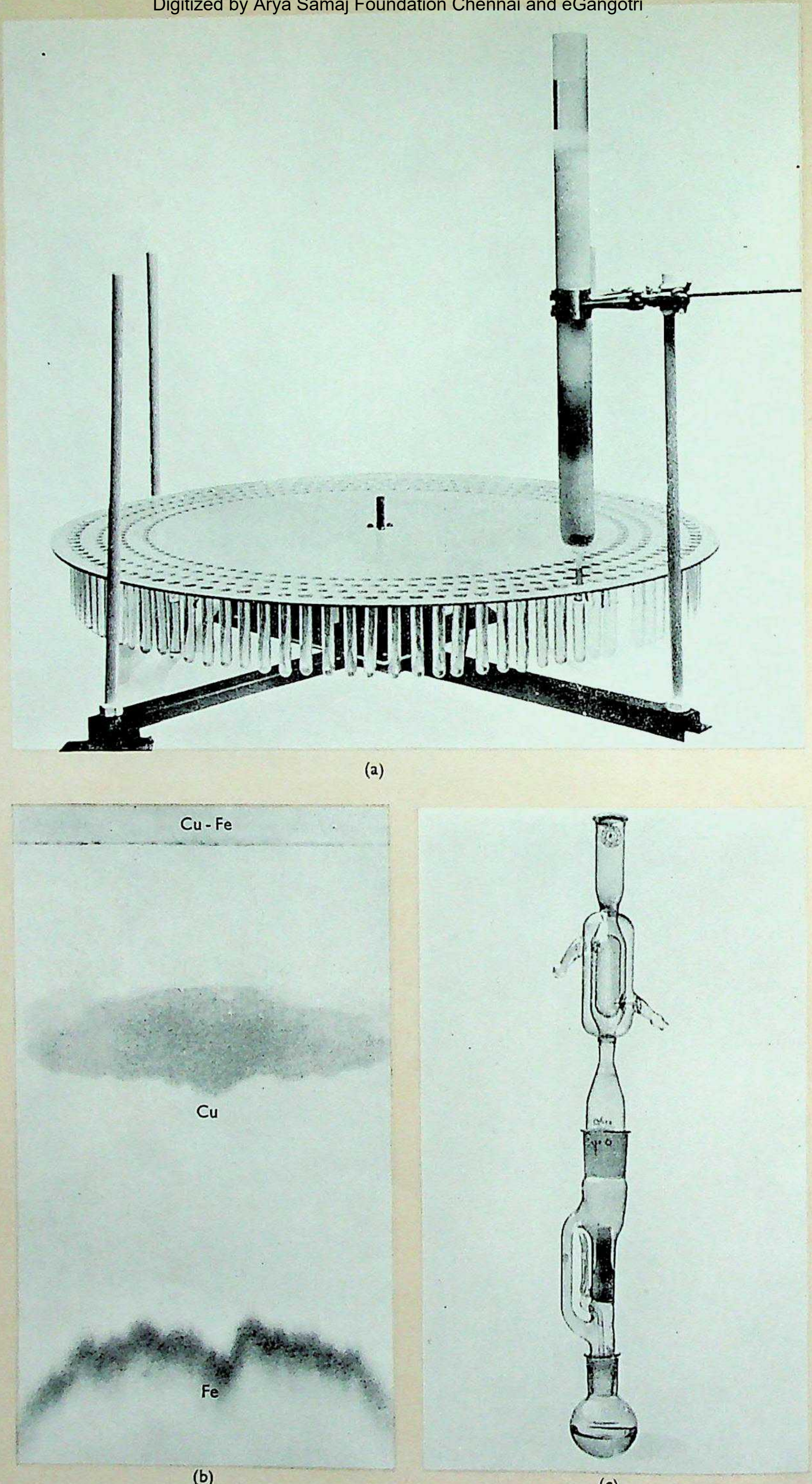


FIGURE 6 – *Paper chromatography can be used for quantitative inorganic analysis.* (a) *Automatic fraction collector used for collecting fractions separated on a column of cellulose.* (b) *Paper chromatogram for quantitative analysis. Using a micropipette, a known volume of the copper-iron solution is placed along a pencil line in a series of spots. The paper is run with benzoylacetone in butanol as the mobile phase, dried, and the coloured bands due to the coloured benzoylacetonates are cut out and then extracted individually in the Soxhlet apparatus* (c) *with ethyl alcohol. The respective extracts are analysed colorimetrically.*

Clearly, the solubility of the inorganic compound in the organic solvent will largely determine how far the particular compound will move from the starting line. Very soluble compounds will move with, or closely behind, the solvent front; less soluble compounds will move to intermediate positions; insoluble compounds will not move at all. To effect a good separation, therefore, there must be an appreciable difference in the respective solubilities, especially if selective extraction plays the major role; if partition effects are important, a slighter difference in the solubilities may produce efficient separation as a result of the repeated partition between the mobile phase and the stationary water held by the paper. While a number of inorganic salts are soluble in organic solvents, it is probable that some salts dissolve as a result of the formation of a soluble complex with the solvent itself. Thus copper chloride will dissolve in butanol saturated with 3N.HCl and moves with an R_f of 0·19, but with collidine it forms a complex and moves with an R_f of 0·76. The deliberate addition of a complex-forming reagent to a solvent mixture can be most effective in separating metals, different complex-forming agents changing the extent of the separation. Whenever complex-formation is employed, the stability of the complex must be assured by the adjustment of the mobile phase to the correct *p*H. A complicating factor, the effect of which cannot be precisely assessed, is that, when a mobile phase containing acid moves down the paper, two fronts can be detected, the upper one being due to the partial retention of the acid by the paper. This may well affect the stability of some of the complexes, with a resultant change in their R_f values.

There have been two distinct lines of approach to the use of paper chromatography for analysis. One is devoted to the separation of the groups of cations associated with the orthodox qualitative analysis, and the other to the development of a scheme which does not depend upon any previous separations. In table II is given a scheme for the former, based on the work of Linstead [10], Lederer [11], and others; it illustrates the various types of solvent employed.

The second approach to the problem of separations dependent entirely on paper chromatography has been made by the Bristol (England) school [12], and is based on the behaviour of a large number of cations with solvents containing a complexing reagent, or with those capable themselves of forming complexes. Three organic solvents—butanol, collidine, and dioxan—have been carefully studied, and it has been found that the cations or their derivatives can be divided into groups, depending on the mobile phase used.

TABLE II

	Solvent	*Mixture separated*
Group 1	Aqueous ammonia.	Pb, Ag, Hg
Group 2*a*	Butanol saturated with 3N.HCl, or ethyl *iso*propylketone with 10 per cent. HCl.	Hg, Bi, Cd, Cu, Pb
Group 2*b*	Butanol saturated with 3N.HCl, or ethyl acetate with 2 per cent. HCl, or acetylacetone saturated with water + 0·5 per cent. by volume of conc. HCl and 25 per cent. by volume of acetone.	Sn, Sb, As
Group 3	*Either* (*a*) Glacial acetic acid + 25 per cent. by volume of methyl alcohol; (*b*) Acetone containing 5 per cent. by volume of water and 8 per cent. by volume of conc. HCl (specific gravity 1·18). *Or* (*a*) 80 per cent. methyl *n*-propyl ketone, 10 per cent. acetone, and 10 per cent. conc. HCl; (*b*) Butanol-acetic acid.	(*a*) Fe, Al, Cr (*b*) Ni, Mn, Co, Zn (*a*) Fe, Co, Mn, Ni (*b*) Cr, Zn, Al
Group 4	Pyridine containing 20 per cent. by volume of water and 1 per cent. KSCN.	Ca, Sr, Ba
Group 5	Methyl alcohol.	Li, Na, K

Group I. Cations moving with butanol-water-benzoylacetone mixture.

Ag^+, Hg^+, Hg^{2+}, Cu^{2+}, Cd^{2+}, As^{3+}, Sn^{2+}, Sn^{4+}, Fe^{3+}.

Group II. Cations moving with collidine-water mixture.

Ag^+, Cu^{2+}, Cd^{2+}, As^{3+}, Sb^{3+}, Zn^{2+}, Mn^{2+}, Co^{2+}, Ni^{2+}, Ca^{2+}, Sr^{2+}, Mg^{2+}, K^+, Na^+.

Group III. Cations moving with dioxan-antipyrine mixture.

Ag^+, Hg^+, Pb^{2+}, Bi^{3+}, Cu^{2+}, Cd^{2+}, As^{3+}, Sn^{2+}, Sn^{4+}.

Although some inorganic compounds move in all solvents, the extent of the movement may be quite different in each. This has marked advantages for analytical purposes.

Two different schemes of procedure have been evolved. The first consists in preparing chromatograms with each of the three solvent mixtures, and identifying the cations by their approximate R_f values and characteristic reactions. The second is based on a sequence of characteristic reactions applied to a number of chromatograms prepared with the butanol-water-benzoylacetone mixture (see table III). Illustrations of the latter are given in figure 3.

As an almost universal reagent for the detection of cations on paper, a mixture of 8-hydroxyquinoline and kojic acid has proved invaluable; it yields complexes which fluoresce or give dark spots in ultra-violet light. The behaviour of a cation with this reagent, coupled with a measurement of its R_f value, is often sufficient for its identification. In addition, many of the standard identification tests (see table I) can be adapted for the detection of ions on filter paper, often with an increase in sensitivity. Some examples are illustrated, but fuller details are available in the published papers. The smallest amount of material which can be chromatographically separated is partly determined by the sensitivity of the identification test; as a rough guide this minimum quantity may be said to be about four times the sensitivity of the test. For example, with cadmium the limit would be about $0{\cdot}2 \times 10^{-6}$ g if detected with the fluorescent reagent, but about 1×10^{-6} g if hydrogen sulphide were used.

The different behaviour of cations with different solvent mixtures as the mobile phase can be used to advantage for two-way processes which will yield improved separations for cations otherwise lying close together. Not only can two different organic solvents, such as collidine and butanol, be used, but the complex-forming reagent also can be changed. The large number of suitable organic solvents and complexing reagents available makes possible a very large number of two-way separations; one of these is illustrated in figure 4, and a number of others have been reported.

TABLE III

Abridged schemes of analysis illustrated in figure 3

Several chromatograms of the same mixture are prepared simultaneously, and then treated separately for analysis.

(*a*) *Ag, Pb, Ni, Cu, Sb, Ba* (*figure 3a*)

- (i) Sprayed with potassium chromate and then treated with sulphur dioxide gas. Pb—yellow; Ag—red.
- (ii) Strip from (i) held over ammonia. Ag spot fades. Sprayed with rhodizonic and then dilute hydrochloric acid. Ba—red; Pb—violet; Ag—grey.
- (iii) Fresh strip sprayed with rubeanic acid and then held over ammonia. Ni—blue; Cu—olive green.
- (iv) Fresh strip sprayed with ammonium sulphide, treated with concentrated hydrochloric acid to dissolve sulphides, and then sprayed with phosphomolybdic acid. Sb—royal blue.

(*b*) *Al, Cu, As, Sn* (*figure 3b*)

- (i) Sprayed with sodium hypophosphite in dilute hydrochloric acid and warmed. As—brown. Then treated with kojic acid—8-hydroxyquinoline spray, held over ammonia, and viewed under ultra-violet light. Al—green fluorescence; Sn—yellow fluorescence. Cu and As—dark, non-fluorescent.
- (ii) Sprayed with hypophosphite to show As, then with rubeanic acid and held over ammonia. Cu—olive-green.

(*c*) *Al, Na, U, Fe, Sn* (*figure 3c*)

- (i) Sprayed with potassium ferrocyanide. U—brown; Fe—blue.
- (ii) Sprayed with zinc uranyl acetate in acetic acid. Na—bluish-green fluorescence under ultra-violet light. Dark spots—Fe, U, and Sn.
- (iii) Treated with kojic acid and 8-hydroxyquinoline spray, held over ammonia, and viewed under ultra-violet light. Al—green fluorescence; Sn—yellow fluorescence; Dark spots—U and Fe.

NOTE. Full details for the analysis of unknown mixtures can be found in reference [12].

The anion associated with the cation in the original metallic salt does not always move to the same position on the paper as the cation, unless it becomes bound to the latter by complex formation. With some mobile phases it is found that the separations of the cations are not affected by the anions present, provided that no completely insoluble salt is formed. On the other hand, it may sometimes be an advantage to have an anion present which will immobilize some of the cations but allow others to move. This idea has been applied to the separation of arsenic from other cations by having as the mobile phase a butanol-water mixture containing ammonium borate, ammonium tartrate, and mannitol, so preventing the other cations from moving. Another aspect of the same idea is used for one of the analytical schemes, when the initial spots on the paper are given a spray with sodium hypobromite and acetic acid to prevent manganese, cobalt, nickel, and some other cations moving with the butanol-benzoylacetone mixture.

Anion analysis has not been closely investigated, although a number of separations have been reported [10–12], and an example of the kind of chromatogram which can be obtained is shown in figure 5. These chromatograms were prepared with a mixture of fifteen parts by volume of butanol, fifteen parts of water, eight parts of pyridine, and one part of 0·88 ammonia as the mobile phase. The following anions were identified: chromate, chloride, and bromide by spraying with silver nitrate and exposing to ultra-violet light; iodide and thiocyanate by spraying with ferric alum. Experiments show that the R_f of the anion is usually independent of the cation with which it is initially associated, and that if the free acid is used it moves with the same R_f. One can, however, visualize cases in which the cation might interfere, so that it is advisable to start with the sodium salts, as is usually done in qualitative analysis.

The separations achieved by paper chromatography can be utilized for quantitative analysis both on the micro-scale and in quantities of up to one gram [10–14]. With micro-quantities the separations can be carried out on a sheet of paper arranged as illustrated in figure 6(*b*). The portions of the paper containing the respective cations are cut out after separation is complete, and then independently extracted with an apparatus like that illustrated in figure 6(*c*). Such a procedure can be used whenever sufficient separation occurs. Similar schemes have been suggested by other workers. The extracted cations may be estimated by a colorimeter or polarograph. For larger quantities, columns of cellulose or thick strips of filter-paper pulp can be used. The separated fractions, as they come through the column, can then be collected in tubes, using the automatic fraction collector [15], as illustrated in figure 6(*a*). These procedures can also be used for preparative work, though no serious use of this fact has as yet been reported; it is, however, an obvious line of development.

In the few years that have elapsed since serious attention was first given to paper chromatography of inorganic compounds, it has been shown that it is likely to be a very useful technique in all fields of science where analysis is needed. Apart from the obvious applications, it may well solve some of the problems associated with the detection and estimation of trace-metals, though some preliminary concentration on an ion-exchange column may first be needed. In inorganic chemistry itself, it will serve to stimulate interest in the extraction of minute quantities of individual metals such as are found in the rare earths, in the preparation and separation of inorganic complexes, and in many problems which have lain dormant for years because of the difficulties of analysis.

(The chromatograms were prepared by Messrs. H. M. Stevens, B. Ellis, and C. D. Bamberger.)

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Book reviews

CHROMATOGRAPHY

Adsorption and Chromatography, *by Harold Gomes Cassidy. Pp.* 360, *with many line diagrams. Interscience Publishers Inc., New York and London.* 1951. 56*s. net.*

This book is a summary of the principles underlying the various methods of analysis—based on adsorption, ion-exchange, and partition—known collectively as chromatography. The author has prepared the text well and added greatly to its value by a detailed bibliography and comprehensive author and subject indexes. The book is valuable not only for summarizing what we know of the physico-chemical principles governing the various chromatographic techniques but for revealing the wide gaps which still exist in our knowledge; one may, however, take some consolation in the recently expressed opinion of Zechmeister that theoretical studies have hitherto had little influence on the practical use of chromatography.

The claim made on page 207, that 'chromatography was invented by Tswett in 1906,' is no longer universally accepted; the prior claims of Day, whose experiments were at once followed up by Engler and Albrecht and others, have certainly hitherto been too lightly dismissed. Furthermore the claim that Schoenbein (page 313) discovered capillary analysis may be challenged by that of Runge. These points are of academic interest, in no way detracting from the practical value of the present book, but it is to be hoped that a detailed study will be made of the early, and today almost completely unknown or ignored, literature of chromatography.

SOME LANGMUIR PAPERS REPUBLISHED

Phenomena, Atoms, and Molecules, *by Irving Langmuir. Pp. xi* + 436, *with several line diagrams. Philosophical Library, New York.* 1950. $10 *net.*

The introduction to this book tells briefly of the conditions under which the author has worked for more than forty years in the research laboratories at Schenectady of the General Electric Company. These laboratories had been established to carry out fundamental research 'in broad fields associated with the work of the company.' Dr Langmuir has published about two hundred papers, which are listed in a bibliography contained at the end of the book. The present volume contains twenty of these papers. They range from the philosophy of scientific work to some of his fundamental contributions to surface physic and chemistry.

It is not easy to understand the basis on which this particular choice has been made. Some of the papers included are lectures given before scientific societies on special occasions; others are of a general review nature; others again are detailed accounts of particular research problems. There appears to have been no attempt to edit them for publication. In different chapters differing symbols are used for the same physical quantity; sometimes the references appear as footnotes, at others they are collected at the end of the chapter—apparently according to the usage of the scientific journal in which the chapter originally appeared as a paper. Similar confusions, which arise from failure to edit the papers, abound throughout the collection. On the dust cover, the publisher refers to this as Dr Langmuir's 'first book.' Such a collection of reprinted and unedited papers hardly warrants that description.

An account of Dr Langmuir's classical researches, written by him today in the light of present knowledge, could be a valuable and stimulating book. Awareness of what could have been done only makes the present collection of reprints the more disappointing. A. R. MILLER

VERTEBRATE LIFE

The Life of Vertebrates, *by J. Z. Young. Pp.* 767, *with numerous line diagrams. Oxford University Press, London.* 1950. 42*s. net.*

To produce a textbook that is at once thoroughly readable and thoroughly usable demands sympathetic outlook, imagination, and literary capacity. It is therefore small wonder that able textbook writers are rarer than able investigators. For comprehensiveness, philosophic grasp, humanity, and the pleasure that it will give the not overspecialized reader, Professor Young's book is, in its department, the most successful effort of the kind that the century has yet yielded. It will do much to determine the direction of zoological class-teaching, which has long shown signs of needing change.

Professor Young's book naturally invites comparison with the excellent standard volume on vertebrates by Parker and Haswell, originally issued in 1898 and now in its sixth edition. This retains its value as the first reference work for the student on matters of morphological fact, since it is fuller and has more illustrations. In every other respect Professor Young's is the superior. It is conceived on a more generous plan, and, though less detailed, is much more comprehensive, notably in its treatment of the geological record. Moreover, Professor Young is concerned with animals as living wholes, with their habits, their bionomics and ecologies, their psychologies, their successes and failures in the struggle for life, and the differentiations and origins of their various physiological systems. His book is thus peculiarly suited to such medical men as are properly interested in that odd vertebrate *Homo sapiens*. In dealing with that species he dwells on certain of its primitive or, rather, infantile features, thanks to which it accommodates itself to the most different environments and is thus exterminating an increasing number of other vertebrate species.

The history of textbooks necessarily reflects the changing interests of the times. For a hundred years from Cuvier—that is, throughout the nineteenth century—zoological textbooks concentrated on comparative anatomy with an increasing stress on development. All this was intensified during the high Darwinian tide. Even the vertebrate manual of T. H. Huxley (1871) was purely morphological. In the classical zoological textbooks of the age, as Professor Young points out, discussion of other aspects was either avoided or relegated to appendices. A change came in the twentieth century with the rise of experimental embryology, biochemistry, comparative physiology, and ecology, but Professor Young is the first to construct a synoptic view of the results attained in all these, and he has combined this with due treatment of important conclusions in palaeontology, comparative psychology, and, above all, with the perennially refreshing old-fashioned natural history. We miss, however, any but the lightest references to genetics. Mammalian structure will be more fully discussed, he tells us, in a second volume, which will also include a survey of comparative embryology. This will surely be welcome, for comprehensive manuals on the study of mammals are antiquated and inadequate, and reference is still not infrequently necessary to Owen's classic of 1866—a hiatus of an extent probably unique in the range of science textbooks.

The illustrations of Professor Young's volume are mostly excellent. We would draw attention to some of those by Miss E. T. Tarlington of the great apes and of the horses. They rival the well-known figures of reptiles with which the late Miss M. E. Durham adorned the Cambridge Natural History, though the work of neither compares in beauty or perhaps in exactness to many of the masterpieces of zoological wood-engraving issued by the London house of Van Voorst in the fifties and sixties of the last century. Nevertheless, the figures exhibit care and feeling. Their clarity, and the skill used in designing them, make us regret the more that the explanations of too many details are relegated to captions. This fatiguing and outmoded device is defensible for conventional abbreviations, as for well-known bones, for parts of the brain, for the great vessels, and so on. In most anatomical figures, however, the name of each relevant part should be plainly printed on it. This method is of respectable antiquity and, since the first edition of Gray's *Anatomy* in 1858, has become universal so far as figures of the human subject are concerned. The sooner it is generally accepted for zoological textbooks the more the student's time and temper will be saved. Some of the figures are rather crowded, and the index should be fuller. All these are minor defects in a major work that is truly delightful and humane. Where nearly everything is good, we would select the section on fishes as attaining the rank of a masterpiece in its own *genre*.

CHARLES SINGER

THE USE OF WOOD

The Coming Age of Wood, *by Egon Glessinger. Pp.* 279, *with several illustrative charts. Martin Secker and Warburg Limited, London.* 1950. 12*s*. 6*d*. *net*.

The author of this book, who for many years before the war was Secretary General of the *Comité International du Bois*, and is now head of the Forest Products branch of F.A.O., writes with unbounded enthusiasm about the possibilities of increasing the yield of raw materials for industry from the forests of the world.

In the first part of the book emphasis is laid on the need for better conservation of the existing forests, and for replacement of wasteful methods of timber 'mining' by the sustained yields of managed forest. This part ends with a chapter on the role of wood in world politics, summarized from an earlier book by the same author.

The second part consists of a pictorial representation, in much simplified diagrammatic form, of the basic principles of forestry, and of the waste involved in various forms of conversion and utilization.

The third part is devoted to various aspects of timber utilization, with particular emphasis on the use of wood as a raw material for chemical processes. The author stresses the importance of finding uses for lignin, which he describes as the enigmatic key to wood-chemistry, and which represents more or less a dead loss to the industries extracting cellulose from wood.

The theme running through the book is integrated utilization—that is, each industry should use that part of the tree most suited to its particular purpose, leaving the residue to be worked up by another process into a different product, the ideal being complete utilization of the tree, instead of the 25 per cent. and 35 per cent. which he estimates are achieved today by the sawmilling and pulping industries respectively.

While it is refreshing to read a book written with such zest, the author's enthusiasm sometimes runs away with him, and he tends to gloss over some of the difficulties involved. Nevertheless the book should do good by bringing home to the general reader the imperative need for husbanding the forest resources of the world, and for utilizing them to the fullest advantage.

W. P. K. FINDLAY

THE GROWTH AND UNITY OF SCIENCE

A Century of Science, 1851–1951, *by specialist authors under the editorship of Herbert Dingle. Pp.* 338. *Hutchinson's Scientific and Technical Publications, London.* 1951. 15*s*. *net*.

This book has been issued in order to summarize and assess scientific progress during the period between the Great Exhibition and the Festival of Britain. It opens appropriately with four chapters on physical aspects of science (the concept of energy, field physics, particle physics, the structure of the atom), and leads on through chemistry (the structure of molecules, the chemical elements) to geology and the earth's atmosphere. Accounts of the constitution and evolution of stars and the structure of the universe complete the first half of the book.

Discussions of organic evolution, the coming of man, and the progress of *Homo sapiens* are followed by others dealing with the development of genetics, embryology, physiology, histology, and biochemistry. Finally, a review of progress in medicine is linked with an account of the growth of psychology. Each subject has been undertaken by an eminent authority in such a way as to present a readable conspectus of the enormous scientific advances of the last hundred years, to which British men of science have made so great a contribution. Professor Dingle's thought-provoking preface and closing chapter emphasize the extension and unification of science during the period under review, the obliteration of arbitrary boundaries between such branches as botany, zoology, and entomology, and the breakdown of the nineteenth-century view of science.

A short account of so vast a subject necessarily tends to become sketchy, as is evident for example in the slight treatment of organic chemistry; but the book will interest intelligent readers having a general acquaintance with science, and it should be of value in helping scientific specialists to view their own work in a proper perspective.

JOHN READ

A CONTRIBUTION TO THE HISTORY OF CHEMICAL INDUSTRY

A History of the Chemical Industry in Widnes, *by D. W. F. Hardie. Pp.* 250, *with* 38 *plates. Imperial Chemical Industries Limited, London.* 1950. 21*s*. *net*.

The two major chemical alkali processes were the Leblanc and ammonia-soda processes and their many ramifications. The electrolytic process could not develop until cheap electrical energy was available. Dr Hardie tells in a very interesting way the story of the evolution of the industry in Widnes. The great names of Muspratt, Gossage, Deacon, Gaskell, Mond, Brunner, Hargreaves, and Hurter come into the account, and the success of the industry was due to the fortunate combination of scientific and business abilities of high order in the different men concerned. The early Leblanc process, much improved in Britain, wasted chlorine and sulphur. The chlorine was recovered by Weldon and Deacon; thousands of tons of sulphur in the form of alkali waste were buried under Widnes or heaped into mounds until Chance perfected the sulphur-recovery process.

It is impossible in a few lines to do justice to the story so well told in this book, which deals both with the scientific and technical and with the social and economic aspects of the industry, bringing the account to modern times. Though there is a large literature not mentioned by the author, unpublished material has been drawn upon and the result is a connected and easily understood narrative. The portraits and illustrations of plant are admirable, and the general style is appropriate to the subject. This is a book which fully justifies all the time and labour that must have been spent on its production, and will be of interest to academic as well as industrial chemists.

J. R. PARTINGTON

POPULAR MATHEMATICS

Mathematics and the Imagination, *by Edward Kasner and James Newman. Pp.* 380, *with numerous line diagrams. G. Bell and Sons Limited, London.* 1949. 15*s. net.*

This is a canvas on which the authors have painted many and diverse scenes. From transfinite numbers to topology, from the googolplex to doughnuts, from transcendental numbers to non-Euclidean geometries, from the calculus to mathematical paradoxes and puzzles, they open our eyes to a succession of imaginative vistas. They delineate these varied scenes with skill and an understanding of the average reader's equipment; their treatment is always fresh and stimulating.

The choice of topics dealt with in this book differs from that in most popular books about mathematics. Such books generally try either to give a philosophical discussion of the concepts of mathematics or to present again, in terms of everyday things, the elementary mathematics that most of us happily forgot as soon as we had cleared the hurdle of school certificate. On the other hand, in this book the authors introduce those topics which are at present the subject of mathematical thought and research. Many of these topics have their origin in apparently simple puzzles and paradoxes. The authors make full use of the opportunity which this approach provides to explain their essence to the non-mathematical reader, and to show how the apparently simple may be, in fact, subtle and replete with new ideas.

Diverse as are the scenes presented to our view, they have a unifying idea. They are all concerned with that mathematical realm where the processes of thought are nearer those of the poet than the scientist; where—without losing its austere logical form—mathematics becomes supreme art as well as science, leading the creative faculties beyond even imagination and intuition.

A. R. MILLER

NUCLEAR CHEMISTRY

Principles of Nuclear Chemistry, *by Russell R. Williams. Pp.* x + 307. *Macmillan and Company Limited, London.* 1950. *D. van Nostrand Company Inc., New York.* 28*s.* 6*d.* ($3.75) *net.*

The author's intention is clearly expressed by the title: the book lays emphasis on principles, not on discussion of details. It covers a wide range of subjects, some of which belong more to nuclear physics than to nuclear chemistry, as, for instance, cascade transformers, van de Graaf generators, and cyclotrons; a description of the preparation of radium-beryllium neutron sources would perhaps have been of greater use to those working in a chemical laboratory. The concentration of isotopes is discussed at some length; it is unfortunate that for the separation by thermal diffusion the formula given by S. Chapman in his very first paper (1919) is quoted, and the fact that a corrected form was published in various papers between 1922 and 1929 is overlooked.

The chemical part comprises chapters on the laboratory treatment of radioelements, the chemical and biological effects of radiations, geological age determinations, tracer studies, and related subjects. Discussing the radiocolloids, the author states that it is now 'generally assumed' that their formation is due to adsorption on solid particles suspended in the liquid phase; in view of the very scanty evidence in favour of this explanation it is to be hoped that some dissenters will continue to challenge it. The table of the periodic system is rather confusing owing to the complete merging of the sub-groups; the symbol of the element Francium is here and in various other places written as Fa, instead of the internationally accepted Fr.

At the end of several chapters numerical exercises and lists of papers for supplementary reading are given. As a smoothly written introduction into a vast field the book will be found useful.

F. A. PANETH

HETEROCYCLIC COMPOUNDS

Heterocyclic Compounds, Volume I. *Editor-in-chief, R. C. Elderfield. Pp. vii* + 703. *John Wiley and Sons, New York; Chapman and Hall Limited, London.* 1950. £6 *net.*

The rapidly expanding knowledge of organic chemistry has made the provision of a series of volumes in all branches of the subject a matter of urgency. This need has perhaps been most keenly felt in the field of heterocyclic compounds, where so much important work has been done in recent years, and its reality is shown by the almost simultaneous appearance of the present volume and a monograph 'The Heterocyclic Derivatives of Phosphorus, Arsenic, etc.' by F. G. Mann in the series 'Heterocyclic Compounds,' edited by A. Weissberger and published by Interscience Publishers, New York.

The present book deals with three-, four-, five-, and six-membered monocyclic compounds containing one hetero atom, either oxygen, nitrogen, or sulphur. These twelve groups are described in eight chapters by separate authors: ethylene and trimethylene oxides; ethyleneimine; trimethyleneimine; furan; thiophen; pyrrole; pyrans, pyrones, thiapyrans and thiapyrones; pyridine, piperidine, and partially reduced pyridines. The chapters reach a very high standard, and although not intended to be completely comprehensive, they give an excellently detailed, up-to-date picture of modern knowledge. They are much more than compilations of facts, and are attractive to read. The very large number of references—something over 3000—makes the book of the greatest value to research workers. The subjects are reviewed from established modern viewpoints, and are illustrated by excellent graphic formulae. This book, in spite of its high price, will find its way to the shelves of most research workers, and the appearance of other volumes (unnumbered) in the series is awaited with interest. Future volumes should be provided with author indexes.

W. BAKER

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

BIOCHEMISTRY

Introduction to Agricultural Biochemistry, *by R. Adams Dutcher, Clifford O. Jensen, and Paul M. Althouse. Pp.* 502. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 48*s. net.*

The Vitamin B Complex, *by F. A. Robinson. Pp.* 668. *Chapman and Hall Limited, London.* 1951. 60*s. net.*

BIOLOGY

Insects and Hygiene, *by J. R. Busvine. Pp.* 482, *with numerous line diagrams. Methuen and Co. Limited, London.* 1951. 3[illegible]*s. net.*

CHEMISTRY

Bibliography of Standard Tentative and Recommended or Recognized Methods of Analysis. *Compiled under the authority of the Analytical Methods Committee of the Society of Public Analysts and other Analytical Chemists. Pp.* 221. *W. Heffer and Sons, Cambridge.* 1951. 25*s. net.*

The Chemical Analysis of Waters, Boiler- and Feed-Waters, Sewage, and Effluents, *by Dennis Dickinson. Pp.* 143, *with line diagrams. Blackie and Sons Limited, London. Second edition.* 1950. 6*s.* 6*d. net.*

The Chemistry of Hydrazine, *by L. F. Andrieth and Betty Ackerson Ogg. Pp.* 244. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 40*s. net.*

The Chemistry of Nonbenzenoid Hydrocarbons, *by Benjamin T. Brooks. Pp.* 615, *with numerous line diagrams. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. Second edition.* 1951. 96*s. net.*

Intermediate Practical Chemistry, *by Sylvanus J. Smith. Pp.* 248, *with numerous line diagrams. Macmillan and Co. Limited, London.* 1951. 8*s. net.*

Organophosphorus Compounds, *by Gennedy M. Kosolapoff. Pp.* 376. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 60*s. net.*

The Structure of Physical Chemistry, *by Sir Cyril Hinshelwood. Pp.* 476, *with several line diagrams. Oxford University Press, London.* 1951. 35*s. net.*

COSMOGONY

The Primeval Atom, *by Georges Lemaître.* (*Translated by Betty H. Korff and Serge A. Korff.*) *Pp.* 186. *D. Van Nostrand Co. Inc., New York; Macmillan and Co. Limited, London.* 1951. 22*s.* 6*d. net.*

CRYSTALLOGRAPHY

Crystal Growth, *by H. E. Buckley. Pp.* 571, *with numerous line and half-tone illustrations. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 72*s. net.*

GENERAL SCIENCE

British Scientists, *by E. J. Holmyard. Pp.* 88, *with several half-tone illustrations. J. M. Dent and Sons Limited, London.* 1951. 6*s. net.*

The Common Sense of Science, *by J. Bronowski. Pp.* 154. *William Heinemann, London.* 1951. 8*s.* 6*d. net.*

A Dictionary of Science, *by E. B. Uvarov and D. R. Chapman. Pp.* 240. *Penguin Reference Books, Harmondsworth, Middlesex. New edition.* 1951. 2*s. net.*

Laboratory Design, *edited by H. S. Colman. Pp.* 393, *with numerous half-tone and line illustrations. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1951. 96*s. net.*

The Physical Basis of Life, *by J. D. Bernal. Pp.* 80. *Routledge and Kegan Paul, London.* 1951. 6*s. net.*

INDUSTRY

Paint Film Defects, their Causes and Cure, *by Manfred Hess. Pp.* 544, *with various half-tone illustrations. Chapman and Hall Limited, London.* 1951. 50*s. net.*

Reviews of Petroleum Technology (*Vol.* 10). *Hon. editor F. H. Garner. Hon. associate editor E. B. Evans. Editor George Sell. Pp.* 350. *The Institute of Petroleum, London.* 1951. 27*s.* 6*d. post free.*

MEDICINE

The History of Pharmacy. A Catalogue of an Exhibition at the Wellcome Historical Medical Museum. *Pp.* 59, *with* 11 *half-tone illustrations. Oxford University Press, London.* 1951. 3*s. net.*

Prehistoric Man in Health and Sickness. A Catalogue of an Exhibition at the Wellcome Historical Medical Museum. *Pp.* 56, *with several half-tone illustrations. Oxford University Press, London.* 1951. 2*s.* 6*d. net.*

PHOTOGRAPHY

Fundamental Mechanisms of Photographic Sensitivity, *by J. W. Mitchell. Pp.* 347, *with numerous line and half-tone illustrations. Butterworths Scientific Publications Limited, London.* 1951. 63*s. net.*

The Photographic Study of Rapid Events, *by W. D. Chesterton. Pp.* 167, *with* 32 *half-tone plates. Oxford University Press, London.* 1951. 21*s. net.*

PHYSICS

Advanced Dynamics (*Vols. I and II*), *by E. Howard Smart. Pp.* 419 *and* 420, *with several line illustrations. Macmillan and Co. Limited, London.* 1951. 40*s. each volume.*

Applied Nuclear Physics, *by Ernest Pollard and William L. Davidson. Pp.* 352, *with numerous half-tone and line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. Second edition.* 1951. 40*s. net.*

Compass Adjustment, *by W. E. May. Pp.* 111. *Hutchinson's Scientific and Technical Publications, London.* 1951. 10*s.* 6*d. net.*

Compléments d'Hydraulique (Deuxième partie), *by L. Escande. Pp.* 248, *with various line illustrations. Dunod, Paris.* 1951. 1900 *fr. net.*

Creep of Metals, *by L. Rotherham. Pp.* 80, *with several line diagrams. The Institute of Physics, London.* 1951. 15*s. net.*

Dielectric Breakdown of Solids, *by S. Whitehead. Pp.* 271, *with several line and half-tone diagrams. Oxford University Press, London.* 1951. 25*s. net.*

Electrophysiologie. Publication du C.N.R.S. *Pp.* 532, *with various line and half-tone diagrams. Centre National de la Recherche Scientifique, Paris.* 1950. £3.2*s. net.*

Introductory Nuclear Physics, *by David Halliday. Pp.* 558, *with various line and half-tone diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1950. 52*s. net.*

Labelled Atoms, *by Raymond Glascock. Pp.* 227, *with numerous line and half-tone illustrations. Sigma Books Limited, London.* 1951. 10*s.* 6*d. net.*

SOCIAL SCIENCE

A Natural History of Man in Britain, *by H. J. Fleure. Pp.* 349, *with numerous colour, half-tone, and line illustrations. Collins, London.* 1951. 21*s. net.*

Social Surveys and Social Action, *by Mark Abrams. Pp.* 153. *Wm. Heinemann, London.* 1951. 8*s.* 6*d. net.*

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Notes on contributors

SIR IAN HEILBRON,

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Was born in 1886 and was educated at the Royal Technical College, Glasgow, and the University of Leipzig. He has held chairs of chemistry in Glasgow, Liverpool, Manchester, and London, and has received many scientific honours, including the Longstaff Medal of the Chemical Society, the Davy Medal of the Royal Society, and the Priestley Medal of the American Chemical Society. Sir Ian played a prominent part in service to the Government during World War II, and is now chairman of the advisory council of the Department of Scientific and Industrial Research. He has worked in many fields of organic chemistry, but is perhaps best known for his contributions to the chemistry of naturally occurring substances, notably the steroids, fat-soluble vitamins, and carotenoids. He is now director of the Brewing Industry Research Foundation.

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Was born in 1911 and was educated at the Imperial College of Science and Technology, London, and at the *Kaiser-Wilhelm Institut für Medizinische Forschung*, Heidelberg. After a short period in industrial research, he joined the staff of the organic chemistry department of the Imperial College of Science and Technology (1937), where eventually he became assistant professor and reader in the University of London. Since 1949, he has been assistant director of the Brewing Industry Research Foundation. He has worked in many fields of organic chemistry and is the author, with a wide circle of collaborators, of numerous scientific publications. He played a notable part in the wartime Anglo-American investigation of the chemistry of penicillin, and a major part of his work has been in the field of natural products and in that of allied synthetic, particularly heterocyclic, substances.

H. G. VEVERS,

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Born in 1916 and educated at St. Paul's School and Magdalen College, Oxford. Before the war did research on bird plumage at Oxford, and took part in expeditions to Greenland, Iceland, and the Faroes. During the war he served in the Royal Air Force as Squadron Leader in the intelligence branch of the Air Staff. In 1946 he joined the staff of the Plymouth laboratory of the Marine Biological Association, where he has worked on natural populations of starfish and on invertebrate pigments. Is at present developing an underwater camera to take photographs of the sea bottom in offshore trawling grounds.

MARY W. PORTER,

B.Sc., D.Sc.,

Was born at King's Lynn, Norfolk, in 1886, and was educated at the Universities of Oxford and Heidelberg, and at Bryn Mawr College, U.S.A. Was Lady Carlisle research fellow of Somerville College, Oxford, from 1919 to 1929, and was elected honorary research fellow of Somerville College in 1948. She has been continuously engaged in research in crystallography since 1917, and since 1931 has worked on the Barker index of crystals. She has contributed fifteen papers to scientific journals, and numerous crystallographic descriptions of new substances included in the papers of other scientists.

KENNETH M. SMITH,

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Was educated at Dulwich College and London University. Trained originally as an entomologist, he has worked for the greater part of his professional life on viruses. Is director of the virus research unit of the Agricultural Research Council at Cambridge. The main work of this unit is the study of plant viruses, but during the last few years a laboratory for the study of viruses attacking insects has been established.

H. ALAN LLOYD,

M.B.E., F.S.A., F.B.H.I.,

Was born in 1890, and was educated at King's College School (London), Liège, Berlin, and the University of Sheffield. In 1910 he went to South Africa, returning for the 1914–18 war. He was a pioneer in the science of the interpretation of aeroplane photographs, writing the original treatise on that subject for the Army.

After the war he was for nearly thirty years with the Mond Nickel Company, retiring in 1948. He is a Fellow of the British Horological Institute and of the Society of Antiquaries.

His published writings include 'The English Domestic Clock,' 'The Work of Samuel Watson,' 'Early English Equation Clocks,' '500 Years of Precision Timekeeping,' 'The Clocks of John Flamsteed and Sir Isaac Newton,' and 'Tides and the Time, a study of Tidal Theories and Dials.'

B. J. MASON,

M.Sc.

Born 1923. Educated at University College, Nottingham. During the war he was a lecturer and later a staff officer in the radar branch of the Royal Air Force. On demobilization he graduated in physics and carried out research on capillary phenomena. In 1948 he was appointed a lecturer in the department of meteorology, Imperial College, London, where he is now in charge of research on cloud physics. He has published a number of papers dealing with theoretical and experimental aspects of condensation and precipitation processes.

F. H. POLLARD,

B.Sc., Ph.D.,

Was educated at Swindon College, and at the University of Bristol under Professor J. W. McBain, later carrying out research with Professor W. E. Garner. He has held responsible teaching appointments at Swindon, Thornbury, and Stoke-on-Trent, returning to the University of Bristol in 1941, where he is now senior lecturer in inorganic chemistry. In addition to his work on chromatography, he is engaged in research on the kinetics of combustion, with special reference to systems containing oxides of nitrogen, and on the production and properties of materials which may have applications as high-temperature refractories. He is the local representative of The Chemical Society.

J. F. W. McOMIE,

M.A., D.Phil.,

Was educated at Haberdashers' Aske's, Hampstead School and Exeter College, Oxford. He was then awarded a Harmsworth senior scholarship to Merton College, Oxford, for two years. He is now a lecturer in organic chemistry at the University of Bristol. He is chiefly interested in the chemotherapy of bacterial diseases and in the complex compounds of metals, but has been associated with research on a variety of organic topics.

Compiled
1999-2000

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हरिद्वार

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REFERENCE BOOK